Appendix A: University of New Hampshire Moored Data Quality Control

Current Meters

The surface current meters (at about 4 meters depth) on the moorings in the North Channel, on Stellwagen Bank, and in Cape Cod Bay were EG&G Vector Measuring Current Meters (VMCM) rented from EG&G Ocean Services. Besides vector averages of the currents from two orthogonal fans, these current meters also recorded temperatures. These current meters were used in the near-surface applications because they were less subject to contamination due to mooring motion (Weller and Davis, 1980). During this experiment, the VMCMs had a poor record of success, with much data lost. At the North Channel mooring, the April to July 1990 velocity record was lost as well as the velocity from January through June 1991. At the Stellwagen Bank mooring, the April through July 1990 velocity record was lost. At the Cape Cod Bay mooring, but the currents from Jan through June 1991 were lost.

The VMCM are designed to average out the wave motion, but have not been extensively tested in this mooring configuration so close to the surface, so some caution should be used when examining the data in detail. The fluxgate compasses in the VMCM current meters have shown non-systematic deviations of 10 degrees in some tests. This error can not be corrected for later because of the way the instrument records the vector averaged currents. Also the compass is located a few meters from the iron mass of the surface float. Still directions should be good to 10 degrees. A limitation to the VMCM velocity measurement is the stall speed of the fans which is 1 cm/sec. As long as the velocities are consistently above this, as they were in Massachusetts Bay, the velocities are measured to within a few cm/sec, (see Table A-1).

Since the VMCMs were near the surface, some contamination with biological growth was expected, and was the reason for the July servicing. The VMCM current meters on Stellwagen bank and Cape Cod Bay showed significant fouling when recovered in January. The records show decreasing velocities sometime after November 1990, and the later part of these records should be treated as if the speeds were attenuated by an unknown amount or discarded. The Stellwagen Bank VMCM fans were so covered with mussels that it was surprising that any current would turn them, but they were still freely turning and the growth just reduced the effectiveness of the pitch on the blades of the fan.

The three deeper current meters on the North Channel mooring (at 25 and 60 meters) and on the Cape Cod Bay mooring (at 25 meter) were UNH Vector Averaging Current Meters (VACM). Besides velocity and temperature each of these measured conductivity with a Sea Bird conductivity sensor whose signal was averaged over the sample interval. The VACMs measure velocity with a rotor and vane, and are subject to contamination due to mooring motion. Therefore, the moorings were designed as taut moorings with compliant elastic elements between the 4 meter VMCM and 25 meter VACM to decouple the buoy motion from the VACM current meters (Wood and Irish, 1987). The VACM rotor stall speed is 2 cm/sec, so should not cause a problem with current measurements in Massachusetts Bay. The compasses are good to within 5 degrees (Woodward and Appell, 1973, Bryden, 1976), and currents to a few cm/sec (McCullough, 1975, Halpern, 1971, Beardsley, 1987) (see Table A-1).

At the North Channel mooring, the 25 meter current meter record from about October 1990 through Jan 1991 was lost due to fouling of the rotor. The VACM at 60 meters was flooded and lost all data from April through July 1990, and the portion from mid-November 1990 through January 1991 was lost when the rotor became fouled in a fish net and line. The 25 meter VACM in Cape Cod Bay was not deployed from July 1990 through Jan 1991 since it was taken to replace the 60 meter current meter in the North Channel while that current meter was repaired.

The 27 meter current meter on Stellwagen Bank was a bottom mounted, EG&G 102 modified by UNH (Irish et al., 1991) to a vector averaging current meter with solid state data storage (SSVACM). It had the same Savonius rotor and vane as the VACM, and the bearings were reworked to the Woods Hole Oceanographic Institution Buoy Group's design. This current meter/bottom instrument also measured temperature, conductivity, and bottom pressure as well as vector averaged velocity. Being bottom mounted, it was not subject to any mooring motion contamination. The instrument was not deployed until mid-July 1990, and was hit and knocked off its anchor by a fishermen and recovered floating in Massachusetts Bay during mid-May 1991. The temperature, conductivity, pressure and velocity records recorded during this time were good, and no observable fouling was seen on the current meter or in the records. The instrument frame was also hit by fishermen and turned a couple of times during the fall period, and there was minor movement of the instrument frame seen in the compass and tilt sensors during the winter due to storms. These should not affect the current records, and the currents are good to a few cm/sec as the VACM above (see Table A-1).

The solar-powered, telemetering-mooring in Stellwagen Basin had a RDI Acoustic Doppler Current Profiler (Irish et al., 1983, Pettigrew et al., 1987) beneath the buoy looking downward. This is the first time this has been done, and only one VACM was deployed by the USGS/WHOI nearby for comparison to see if the observations were contaminated by buoy motion. This is the same motion that is claimed to be averaged out of shipboard mounted Doppler profilers so there should be no major problem. The Doppler velocity records are good except for the gap between December 1990 when a ship hit the buoy, and broke an underwater cable connecting the power to the Doppler profiler and January 1991 when the mooring was repaired.

There was some uncertainly in the time base in the Doppler during the fall due to a clock failure, but this uncertainty is of the order of 10 minutes and not significant in any low frequency studies here. This may be noticeable in the tidal analysis, so the summer to fall observations were not analyzed for their tidal content. The velocities were returned as 4.3 meter depth averages starting at 8.3 meters and continuing to the bottom. Some caution should be taken when using the data closest to the bottom as it may be contaminated by bottom reflection. The data is good to a few cm/sec (Pettigrew and Irish, 1983, Pettigrew et al., 1986) (see Table A-1). The compass for the Doppler profiler was mounted in the pressure case about 2 meters below the steel surface float. Comparison of the M2 tidal ellipses with the nearby USGS VACM current meter at 75 meters depth, shows a systematic 15-20 degree difference, with the Doppler currents rotated counter clockwise as if they were not corrected for magnetic deviation and the Doppler velocities are about 8 percent higher.

Temperature

At the 4 meter VMCM in the North Channel mooring, the April to July 1990 temperature was lost. At the 4 meter VMCM in Stellwagen Bank mooring, the April through July 1990 temperature records was lost. At the 4 meter VMCM in the Cape Cod Bay mooring, the entire temperature record was obtained, but the currents from Jan through June 1991 were lost. The VMCM temperatures are measured to better than 0.1 deg C (see Table 2.2-2).

The 25 meter VACM in the North Channel mooring returned an the entire record. The 60 meters VACM in the North Channel was flooded and lost all data from April through July 1990. The 25 meter VACM in Cape Cod Bay was not occupied while the flooded current meter was repaired from July 1990 through Jan 1991. The VACM temperature sensors were not calibrated before this experiment, but the previous calibrations were used and checked with a single point at laboratory temperature. The temperatures are measured to about 0.1 deg C (see Table A-1).

The Stellwagen Bank bottom-instrument Sea Data temperature sensor was also not fully calibrated for this experiment, but an earlier calibration was used and standardized with a single point at laboratory temperature. Resulting temperatures are good to 0.05 deg C (see Table A-1).

The temperatures at the Stellwagen Basin mooring were measured by Sea Bird Temperature sensors (Pederson, 1969). Past history has shown these sensors drift slowly at a rate of less than 0.003 deg/year, so that with no corrections, the temperature are good to better than 0.01 deg C. These sensors were also used for the standardization of other temperature sensors in the current meters in the laboratory before deployment.

Comparisons of all the time series temperatures and CTD profiles were attempted, but the spatial separation of most of the CTD profiles was too great for useful results. The UNH self contained CTD (Irish et al., 1989) was used in the April Deployment and the June Recovery for comparison near the moorings, and the temperatures agreed as well as could be expected.

Salinity

In situ time series of measurements of oceanographic salinity are the hardest measurement to make of the standard physical oceanographic observations (temperature, pressure, salinity and water velocity). The limiting factor is the contamination of the conductivity sensor electrodes with biological growth and/or the presence of suspended particulate matter in the cell (Irish, 1990). Both of these cause a drift toward lower conductivity (toward false indication of fresher water), but these effects can often be removed if comparisons are done with nearby CTD profiles. Unfortunately during the Massachusetts Bay Experiment, not enough comparisons were made close to the mooring for full correction of all records. This correction for drift will take care of any low-frequency drift, but still the higher frequency signals are not as strongly effected by the slow rate of drift and can be believed without correction. There can also be a problem with the conductivity sensor itself where the potting around the cell breaks loose and lets sea water short out the wires and causes an offset toward higher salinities often as large as 1 psu.

During the Massachusetts Bay Experiment, the conductivities were measured with Sea Bird conductivity sensors (Pederson and Gregg, 1979), which were calibrated at the North West Regional Calibration center in Bellevue Washington before deployment. The data system sampled the temperature each minute and averaged the results to hourly values to prevent any aliasing (Irish et al., 1987) the same as for temperature. The conductivity sensor was paired with a temperature sensor on the mooring, with the conductivity cell horizontal for maximum flushing. Trialkyltin antifouling impregnated cylinders were attached to both ends of the conductivity cell to reduce biological fouling, and the inside of the conductivity cell guard was painted with anti-fouling compound to further reduce the potential of fouling.

The conductivity and temperature time series obtained were converted to salinity using the UNESCO 1980 equations of state of seawater with the Practical Salinity Scale of 1978 (Fofonoff and Millard, 1983) as described in Brown et al. (1983a) and Irish (1985). Once converted to salinity, the observations were compared with CTD observations where appropriate and corrections applied. Also potential density time series (sigma theta) were calculated at the Stellwagen Basin mooring, and the series at various depths checked to make sure that there were no consistent stretches were heavier water was found over lighter water. Again corrections were made where appropriate. This yields a consistent set of observations for analysis.

The salinity record from the North Channel mooring at 25 meters was complete, except that (1) the portion from July through September 1990 appears to have a high salinity with drift toward lower salinity, which then appears to correct itself. No explanation can be reached for this behavior which has not been seen before. However this sensor also misbehaved in the portion of the record from February through May 1991 which appears offset toward higher salinity by about 1 psu. Since the record terminated before the recovery CTD profiles, accurate adjustment could not be made.

The salinity record from the North Channel mooring at 60 meters was lost from April through July 1990 when the current meter flooded. After being deployed during the July turnaround, the record is good to within 0.1 psu. The Salinity record from the Cape Cod mooring at 25 meters was lost from July 1990 through January 1991. The start and ending portion of the records are good, except the batteries prematurely ran down and terminated the record in early May 1991. The salinities are good to 0.1 psu. (see Table A-1)

The Stellwagen Basin salinities allowed comparisons between CTD and different levels to produce a consistent corrected data set. UNH CTD's at the start of the experiment showed no initial offset due to sensor problems. Comparisons at the end of the experiment showed typical drifts toward lower conductivity of about 0.2 psu. The deepest (60 meter) record had an accumulated drift of twice that much. However, comparing the 60 and 45 meter record, it became apparent that a relative drift started in early November and continued to the January 1991 servicing. During this time the sensor drifted about 0.3 psu, and it is thought that this was due to suspended sediment which moved down from the shallower water, during the winter time and slowly filled the cell, reducing the readings. With this drift, the cell drifted about the same as the others. Therefore, in addition to biological fouling in the shallow waters, consideration must be made of sediment contamination near the bottom. This drift as estimated by the comparison with neighboring conductivity implies that most of the sediment was confined in the lower part of the water column, and did not exist as large events as seen in the bottom records in the Gulf of Maine (Irish, 1990). The salinity records from the Stellwagen Basin mooring were corrected so that salinities are good to 0.1 psu (see Table A-1).

Pressure

Pressures were measured with Paroscientific Digiquartz pressure sensors (Warn and Larsen, 1982). All sensors were calibrated for pressure and temperature sensitivity at the University of New Hampshire before the deployment, and calibration results compared with past history (Brown et al., 1983b, Irish, 1990). The pressure sensors at Gloucester and Provincetown were mounted on a bracket bolted to a pier at the Coast Guard facility docks. The sensors were not moved during the experiment when the data recorders were serviced to give a standard baseline. The sensors were powered at voltages exceeding the voltage at which they become voltage sensitive to eliminate any voltage effects.

The limiting factor in oceanographic pressure measurements is sensor drift, which is subjectively removed as a decaying exponential of the form

$$\text{drift} = \text{Mean} + \text{Amplitude} * \exp(\text{rate} * \text{time})$$

by least squares techniques (Irish, 1990). Additionally, the quartz crystal in the time base of the recorder also has a temperature sensitivity which will affect the measurement. Again the clocks were calibrated for temperature sensitivity and these results used to removed any effects from the data as described by Irish (1990). The resulting pressures are good to 0.1 dbar (Brown et al., 1983) (see Table A-1).

A limitation of the bottom mounted pressure observation on Stellwagen Bank is the stability of the bottom instrument frame. There was some observed movement in this frame as detected the current meter compass and by two-axis tilt sensors. During the fall, the frame was hit by fishermen three times and rotated nearly 90 degrees. During the winter, the frame again showed some tilt changes, but this time they were not as sudden, occurring over a day rather than a single sample, and are related to the winter storms. The rotor speed was recorded as well as the vector averages, and while the vector averages show nice, consistent tidal currents, the speed showed elevated readings which are attributed to excessive wave currents which probably eroded the sand around the frame allowing it to tilt. The resulting offsets in the pressure record are not clearly visible, (i.e. any effects are in the 0.01 dbar range where environmental signals are at the 0.1 dbar level) but the tilt and compass records give us the times of potential baseline offsets. Again after removal of sensor drifts, the pressures are good to 0.1 dbar (see Table A-1) and are conditional on the known times that the frame moved slightly.

The pressure record at Gloucester suffered loss of data from March 1990 to July 1990 due to a leak in the pressure case which was not assembled properly. Then the recorded batteries failed prematurely, ending the record at the end of April 1991. The bottom pressure record in the North Channel did not appear to have any movement and no other problems. The Provincetown record was good for the entire time without problems. These records are good to 0.1 dbars (see Table A-1).

Table A-1. Nominal Sensor Accuracy and Precision

Sensor	Manufacturer	Method	Accuracy	Precision
Pressure	Paroscientific	Quartz	0.1 dbar*	0.01 dbar
Temperature	Sea Data Inc.	Thermistor	0.05 deg	0.005 deg
	Sea Bird	Thermistor	0.005 deg	0.001 deg
	EG&G VACM	Thermistor	0.1 deg	0.001 deg
	EG&G VMCM	Thermistor	0.1 deg	0.002 deg
Conductivity	Sea Bird	Electrode	0.01 S/m*	0.0005 S/m
Velocity	EG&G VACM	Rotor/Vane	5 cm/sec	3 cm/sec
	EG&G VMCM	Two Fans	5 cm/sec	3 cm/sec
	UNH SSVACM	Rotor/Vane	5 cm/sec	3 cm/sec
	RDI ADCP	Acoustic	5 cm/sec	5 cm/sec

* After removal of drift due to sensor creep or fouling.

Appendix B: Bulk Formulae for the Different Atmosphere-ocean Heat Flux Components

The local net heat flux across the air-sea interface Q can be approximated by represented the following sum of heat fluxes:

$$Q = Q_s - Q_b - Q_e - Q_h \quad ,$$

where Q_s = incoming short wave radiation to the sea surface;
Q_b = effective long wave radiation from the sea surface;
Q_e = latent heat transfer from the sea surface; and
Q_h = sensible heat transfer from the sea surface.

The incoming solar radiation heat flux was not measured, but the following climatological monthly mean values (according Hopkins and Raman, 1987) of Q_s (gm-cal/cm^2) could be used for heat budget;

January	229.9
February	296.6
March	506.7
April	643.4
May	740.0
June	766.8
July	726.8
August	643.4
September	523.5
October	396.7
November	283.4
December	229.9

The effective backradiation Q_b (gm-cal/cm^2/d) was computed according to the relation (from Berliand and Berliand, 1952; Huang and Park, 1975):

$$Q_b = 1.1365x10^{-7}(t_w + 273.15)^4(0.39 - 0.05\left(e_a\right)^{\frac{1}{2}}\right)(1 - 0.0068c^2) \quad ,$$

where t_w is sea surface temperature (^{o}C);

e_a is water vapor pressure (mb) of air at anemometer height
(10m)
(see below); and
c = % cloud cover

The latent heat flux $Q_e(gm - cal/cm^2/d)$ (Brown and Beardsley, 1978; Sverdrup, Johnson and Fleming, 1946) was calculated according to

$$Q_e = EL \quad ,$$

where the coefficient of latent heat L is

$$L(cal/gm) = 596 - 0.52t_w$$

the evaporative mass flux is

$$E(gm/cm^2/d) = 0.007(e_w - e_a)W \quad ,$$

and W is wind speed (knots). The water vapor pressure at the sea surface e_w and at anemometer height e_a are determined as follows. The water vapor pressure at the sea surface temperature, e_w was determined from

$$e_w(mb) = esd \circ (1 - 5.37 \times 10^{-4}S) \quad ,$$

where e_{sd} is the saturated water vapor pressure of distilled water evaluated by the relation shown below but at sea water temperature t_w (°C) measured at the Boston buoy; (salinity, S, was assumed to be 33 psu). The saturated water vapor pressure at anemometer height e_{sd} is computed according to an expression based on Dutton (1986)

$$e_{sd} = 6.11\ exp[\frac{L(t_a)}{0.1104}\ \frac{t_a}{(273.16)(t_a + 273.16)}] \quad ,$$

where t_a is the air temperature (°C) at anemometer height on the Boston Buoy.

The water vapor pressure at anemometer height was determined from relative humidity RH measurements at Logan airport according to

$$e_a = RH e_{sd} \quad .$$

Sensible heat flux Q_h was determined from latent heat flux according to

$$Q_h = BQ_e \quad ,$$

where the Bowen ratio B (Bowen, 1926) is

$$B = 0.49(\frac{t_w - t_a}{e_w - e_a}) \quad .$$

Appendix H: Station Lists

Table H1: Station list for UMB hydrographic cruise on April 13, 1990.

Section	Station	Latitude		Longitude		Date	Time
Boston	bo1	42	22.00	70	55.34	4/13/90	0934
	bo2	42	22.52	70	51.47	4/13/90	1008
	bo3	42	22.21	70	46.91	4/13/90	1031
	bo4	42	23.11	70	42.66	4/13/90	1125
	bo5	42	23.50	70	38.40	4/13/90	1157
	bo6	42	23.76	70	34.26	4/13/90	1228
	bo7	42	24.20	70	30.31	4/13/90	1305
	bo8/ca6	42	24.59	70	26.38	4/13/90	1350
	ca5	42	27.58	70	28.85	4/13/90	1430
	ca4	42	29.83	70	30.64	4/13/90	1455
	ca3	42	32.03	70	32.42	4/13/90	1535
	ca2	42	34.24	70	34.22	4/13/90	1556
	ca1	42	36.54	70	36.02	4/13/90	1629

Table H2: Station list for UMB hydrographic cruise on April 27–28, 1990.

Section	Station	Latitude		Longitude		Date	Time
Gloucester	gl1	42	32.72	70	41.10	4/27/90	2012
	gl2	42	34.78	70	38.38	4/27/90	2042
Cape Ann	ca1	42	36.53	70	36.04	4/27/90	2104
	ca2	42	34.29	70	34.27	4/27/90	2144
	ca3	42	32.09	70	32.38	4/27/90	2232
	ca4	42	29.97	70	30.20	4/27/90	2300
	ca5	42	27.65	70	28.82	4/27/90	2342
Salem	ca6/sa6	42	24.68	70	26.45	4/28/90	0022
	sa5	42	25.83	70	29.59	4/28/90	0057
	sa4	42	27.02	70	33.12	4/28/90	0124
	sa3	42	28.25	70	36.28	4/28/90	0157
	sa2	42	29.49	70	40.33	4/28/90	0240
	sa1	42	30.76	70	43.86	4/28/90	0310
Nahant	na4	42	28.36	70	46.66	4/28/90	0350
	na2	42	26.30	70	49.40	4/28/90	0416
	na2	42	24.10	70	52.20	4/28/90	0455
Boston	bo1/na1	42	22.03	70	55.15	4/28/90	0520
	bo2	42	22.41	70	51.33	4/28/90	0548
	bo3	42	22.69	70	46.69	4/28/90	0623
	bo4	42	23.12	70	42.63	4/28/90	0652
	bo5	42	23.50	70	38.48	4/28/90	0718
	bo6	42	23.76	70	34.26	4/28/90	0748
	bo7	42	24.20	70	30.31	4/28/90	0832
	bo8/co6	42	24.64	70	26.41	4/28/90	0902
Cohasset	co5	42	23.01	70	29.37	4/28/90	0935
	co4	42	21.20	70	33.17	4/28/90	1007
	co3	42	19.61	70	36.88	4/28/90	1055
	co2	42	17.20	70	40.49	4/28/90	1129
	co1	42	15.97	70	44.19	4/28/90	1153
Scituate	sc1	42	12.01	70	37.99	4/28/90	1240
	sc2	42	13.80	70	36.51	4/28/90	1340
	sc3	42	15.61	70	31.70	4/28/90	1347
	sc4	42	17.25	70	29.03	4/28/90	1414
	sc5	42	19.06	70	25.49	4/28/90	1452
	sc6	42	20.76	70	21.91	4/28/90	1528
	sc7	42	22.58	70	18.30	4/28/90	1559
	sc8	42	24.38	70	14.60	4/29/90	1639
	sc9/hu10	42	26.06	70	11.03	4/28/90	1713

Table H2 (Con't): Station list for cruise on April 27–28, 1990.

Section	Station	Latitude		Longitude		Date	Time
Humarock	hu9	42	23.01	70	12.95	4/28/90	1752
	hu8	42	20.00	70	15.07	4/28/90	1823
	hu7	42	17.00	70	16.85	4/28/90	1854
	hu6	42	15.70	70	20.50	4/28/90	1929
	hu5	42	14.31	70	24.00	4/28/90	1958
	hu4	42	12.97	70	27.52	4/28/90	2026
	hu3	42	11.62	70	31.01	4/28/90	2118
	hu2	42	10.30	70	34.40	4/28/90	2149
	hu1	42	8.87	70	37.85	4/28/90	2215
Sandwich	sw1	41	47.89	70	27.35	4/28/90	0856
	sw2	41	48.34	70	23.62	4/28/90	0929
	sw3	41	48.88	70	19.85	4/28/90	0954
	sw4	41	49.41	70	16.00	4/28/90	1027
	sw5	41	49.95	70	12.20	4/28/90	1051
	sw6	41	50.49	70	8.46	4/28/90	1114
Wellfleet	we2	41	53.71	70	9.09	4/28/90	1140
Manomet	ma6	41	56.93	70	9.77	4/28/90	1205
	ma5	41	56.49	70	13.87	4/28/90	1234
	ma4	41	55.96	70	17.93	4/28/90	1326
	ma3	41	55.44	70	21.98	4/28/90	1351
	ma2	41	54.94	70	26.02	4/28/90	1424
	ma1	41	54.36	70	30.12	4/28/90	1456
South Pl.	sp1	41	56.43	70	31.99	4/28/90	1528
Plymouth	pl1	41	58.50	70	33.78	4/28/90	1550
	pl2	41	59.61	70	30.51	4/28/90	1620
	pl3	42	.70	70	27.26	4/28/90	1644
	pl4	42	1.84	70	23.93	4/28/90	1708
	pl5	42	2.91	70	20.71	4/28/90	1737
	pl6	42	4.06	70	17.39	4/28/90	1801
	pl7	42	5.20	70	14.27	4/28/90	1828
Provincetown	pr2	42	7.46	70	14.96	4/28/90	1856
Duxbury	du7	42	9.80	70	15.73	4/28/90	1917
	du6	42	9.11	70	19.15	4/28/90	1945
	du5	42	8.35	70	22.62	4/28/90	2005
	du4	42	7.61	70	26.28	4/28/90	2035
	du3	42	6.87	70	29.69	4/28/90	2106
	du2	42	6.60	70	32.95	4/28/90	2129
	du1	42	5.90	70	36.43	4/28/90	2152
	du1a	42	8.20	70	38.00	4/28/90	2215

Table H3: Station list for UMB hydrographic cruise on June 29, 1990.

Section	Station	Latitude		Longitude		Date	Time
Boston	bo1	42	22.10	70	55.00	6/29/90	0825
	bo2	42	22.56	70	51.65	6/29/90	0854
	bo3	42	22.65	70	46.99	6/29/90	0918
	bo4	42	23.11	70	42.73	6/29/90	1010
	bo5	42	23.40	70	38.52	6/29/90	1034
	bo6	42	23.84	70	34.52	6/29/90	1058
	bo7	42	22.14	70	30.37	6/29/90	1152
	bo8/ca6	42	24.53	70	26.37	6/29/90	1215
Cape Ann	ca5	42	27.55	70	28.94	6/29/90	1255
	ca4	42	29.84	70	30.65	6/29/90	1312
	ca3	42	31.92	70	32.40	6/29/90	1353
	ca2	42	34.29	70	34.26	6/29/90	1408
	ca1	42	36.50	70	36.09	6/29/90	1447
Salem	sa4	42	27.10	70	33.10	6/29/90	1544
	sa3	42	28.29	70	36.92	6/29/90	1602
	sa2	42	29.43	70	40.38	6/29/90	1640
	sa1	42	30.64	70	44.14	6/29/90	1659

Table H4: Station list for UMB hydrographic cruise on July 24–26, 1990.

Section	Station	Latitude		Longitude		Date	Time
Gloucester	gl1	42	32.72	70	41.10	7/24/90	0139
	gl2	42	34.78	70	38.38	7/24/90	0211
Cape Ann	ca1	42	36.53	70	36.04	7/24/90	0238
	ca2	42	34.29	70	34.27	7/24/90	0328
	ca3	42	32.09	70	32.38	7/24/90	0407
	ca4	42	29.97	70	30.20	7/24/90	0434
	ca5	42	27.65	70	28.82	7/24/90	0836
	ca6/sa6	42	24.68	70	26.45	7/25/90	0930
Salem	sa5	42	25.83	70	29.59	7/25/90	1005
	sa4	42	27.02	70	33.12	7/25/90	1132
	sa3	42	28.25	70	36.78	7/25/90	1158
	sa2	42	29.49	70	40.33	7/25/90	1244
	sa1	42	30.76	70	43.86	7/25/90	1314
Nahant	na3	42	26.31	70	49.35	7/25/90	1435
	na2	42	24.10	70	52.29	7/25/90	1526
Boston	bo1/na1	42	22.03	70	55.15	7/25/90	1557
	bo2	42	22.41	70	51.33	7/25/90	1629
	bo3	42	22.69	70	46.69	7/25/90	1703
	bo4	42	23.12	70	42.63	7/25/90	1734
	bo5	42	23.50	70	38.48	7/25/90	1814
	bo6	42	23.76	70	34.26	7/25/90	1845
	bo7	42	24.20	70	30.31	7/25/90	1932
	bo8/co6	42	24.64	70	26.41	7/25/90	1958
Cohasset	co5	42	23.01	70	29.37	7/25/90	2028
	co4	42	21.20	70	33.17	7/25/90	2059
	co3	42	19.61	70	36.88	7/25/90	2145
	co2	42	17.20	70	40.49	7/25/90	2215
	co1	42	15.97	70	44.14	7/25/90	2245
Scituate	sc1	42	12.01	70	37.99	7/25/90	2330
	sc2	42	13.80	70	36.51	7/26/90	0002
	sc3	42	15.61	70	31.70	7/26/90	0035
	sc4	42	17.40	70	29.20	7/26/90	0107
	sc5	42	19.06	70	25.49	7/26/90	0150
	sc6	42	20.76	70	21.91	7/26/90	0225
	sc7	42	22.58	70	18.30	7/26/90	0312
	sc8	42	24.38	70	14.60	7/26/90	0350
	sc9/hu10	42	26.06	70	11.03	7/26/90	0420

Table H4 (Con't): Station list for cruise on July 24–26, 1990.

Section	Station	Latitude		Longitude		Date	Time
Humarock	hu9	42	23.01	70	12.95	7/26/90	0459
	hu8	42	20.00	70	15.07	7/26/90	0534
	hu7	42	17.00	70	16.85	7/26/90	0600
	hu6	42	15.70	70	20.50	7/26/90	0637
	hu5	42	14.31	70	24.00	7/26/90	0707
	hu4	42	12.97	70	27.52	7/26/90	0737
	hu3	42	11.62	70	31.01	7/26/90	0818
	hu2	42	10.30	70	34.40	7/26/90	0843
	hu1	42	8.87	70	37.85	7/26/90	0908
Sandwich	sw1	41	47.88	70	27.34	7/25/90	1039
	sw2	41	48.33	70	23.62	7/25/90	1117
	sw3	41	48.85	70	19.87	7/25/90	1145
	sw4	41	49.40	70	16.00	7/25/90	1223
	sw5	41	49.95	70	12.20	7/25/90	1248
	sw6	41	50.50	70	8.43	7/25/90	1312
Wellfleet	we2	41	53.70	70	9.10	7/25/90	1342
Manomet	ma6	41	56.93	70	9.76	7/25/90	1412
	ma5	41	56.47	70	13.93	7/25/90	1443
	ma4	41	55.95	70	17.97	7/25/90	1508
	ma3	41	55.45	70	22.00	7/25/90	1533
	ma2	41	54.93	70	26.04	7/25/90	1611
	ma1	41	54.33	70	30.16	7/25/90	1639
South Pl.	sp2	41	56.43	70	32.00	7/25/90	1705
Plymouth	pl1	41	58.51	70	33.79	7/25/90	1727
	pl2	41	59.62	70	30.49	7/25/90	1755
	pl3	42	.70	70	27.26	7/25/90	1818
	pl4	42	1.84	70	23.88	7/25/90	1843
	pl5	42	2.94	70	20.67	7/25/90	1915
	pl6	42	4.07	70	17.36	7/25/90	1939
	pl7	42	5.21	70	14.23	7/25/90	2003
Provincetown	pr2	42	7.47	70	14.95	7/25/90	2031
Duxbury	du7	42	9.79	70	15.65	7/25/90	2057
	du6	42	9.10	70	19.16	7/25/90	2126
	du5	42	8.34	70	22.61	7/25/90	2151
	du4	42	7.82	70	26.30	7/25/90	2216
	du3	42	7.10	70	29.70	7/25/90	2246
	du2	42	6.49	70	32.96	7/25/90	2308
	du1	42	5.93	70	36.16	7/25/90	2330
	du1a	42	8.21	70	38.00	7/25/90	2355

Table H5: Station list for UMB hydrographic cruise on September 28, 1990.

Section	Station	Latitude		Longitude		Date	Time
Boston	bo1	42	22.16	70	54.99	9/28/90	0853
	bo2	42	22.57	70	51.71	9/28/90	0942
	bo3	42	22.58	70	46.98	9/28/90	0957
	bo4	42	23.08	70	42.79	9/28/90	1035
	bo5	42	23.46	70	38.36	9/28/90	1056
	bo6	42	23.85	70	34.28	9/28/90	1115
	bo7	42	24.16	70	30.39	9/28/90	1214
	bo8/ca6	42	24.58	70	26.32	9/28/90	1239
Cape Ann	ca5	42	27.59	70	28.99	9/28/90	1314
	ca4	42	29.87	70	30.46	9/28/90	1331
	ca3	42	31.92	70	32.38	9/28/90	1404
	ca2	42	34.35	70	34.32	9/28/90	1423
	ca1	42	36.49	70	36.08	9/28/90	1455
Salem	sa3	42	28.29	70	36.98	9/28/90	1547
	sa2	42	29.44	70	40.38	9/28/90	1620
	sa1	42	30.64	70	44.19	9/28/90	1640
Nahant	na3	42	26.26	70	49.42	9/28/90	1730
	bo1a	42	22.02	70	55.14	9/28/90	1801

Table H6: Station list for UMB hydrographic cruise on October 16–18, 1990.

Section	Station	Latitude		Longitude		Date	Time
Gloucester	gl1	42	32.80	70	41.26	10/16/90	1840
	gl2	42	34.89	70	38.38	10/16/90	1910
Cape Ann	ca1	42	36.57	70	36.04	10/16/90	1934
	ca2	42	34.29	70	34.27	10/16/90	2019
	ca3	42	31.99	70	32.46	10/16/90	2105
	ca4	42	29.86	70	30.71	10/16/90	2138
	ca5	42	27.65	70	26.88	10/16/90	2221
	ca6/sa6	42	24.60	70	26.44	10/16/90	2258
Salem	sa3	42	28.22	70	36.80	10/17/90	0034
	sa2	42	29.45	70	40.37	10/17/90	0130
	sa1	42	30.70	70	43.90	10/17/90	0204
hline Nahant	na4	42	28.41	70	46.69	10/17/90	0246
	na3	42	26.30	70	49.40	10/17/90	0321
	na2	42	24.07	70	52.28	10/17/90	0357
Boston	bo1	42	22.20	70	54.88	10/17/90	0430
	bo2	42	22.51	70	51.36	10/17/90	0501
	bo3	42	22.54	70	46.87	10/17/90	0530
	bo4	42	23.13	70	42.36	10/17/90	0613
	bo5	42	23.48	70	38.39	10/17/90	0647
	bo6	42	23.48	70	34.28	10/17/90	0714
	bo7	42	24.19	70	30.24	10/17/90	0803
	bo8/co6	42	24.62	70	26.39	10/17/90	0834
Cohasset	co5	42	23.00	70	29.44	10/17/90	0909
	co4	42	21.23	70	33.15	10/17/90	0942
	co3	42	19.65	70	36.86	10/17/90	1029
	co2	42	17.73	70	40.62	10/17/90	1100
	co1	42	15.99	70	44.06	10/17/90	1130
Scituate	sc1	42	11.97	70	39.97	10/17/90	1221
	sc2	42	13.77	70	36.43	10/17/90	1253
	sc3	42	15.56	70	31.66	10/17/90	1330
	sc4	42	17.27	70	29.08	10/17/90	1357
	sc5	42	19.11	70	25.40	10/17/90	1443
	sc6	42	20.78	70	21.86	10/17/90	1511
	sc6A	42	21.51	70	20.31	10/17/90	1523
	sc7	42	22.63	70	18.24	10/17/90	1605
	sc8	42	24.48	70	14.60	10/17/90	1645
	sc9/HU	42	26.07	70	10.97	10/17/90	1713

Table H6 (Con't): Station list for cruise on October 16-18, 1990

Section	Station	Latitude		Longitude		Date	Time
Humarock	hu9	42	23.05	70	12.96	10/17/90	1805
	hu8	42	20.07	70	15.20	10/17/90	1843
	hu7	42	17.02	70	16.92	10/17/90	1915
	hu6	42	15.70	70	20.46	10/17/90	1947
	hu5	42	14.25	70	24.02	10/17/90	2016
	hu4	42	12.94	70	27.57	10/17/90	2043
	hu3	42	11.61	70	31.10	10 17/90	2138
	hu2	42	10.27	70	34.50	10/17/90	2205
	hu1	42	8.83	70	38.05	10/17/90	2231
Duxbury	du1	42	5.84	70	36.08	10/17/90	2312
	du2	42	6.47	70	32.88	10/17/90	2340
	du3	42	7.11	70	29.68	10/18/90	0003
	du4	42	7.81	70	26.29	10/18/90	0028
	du5	42	8.32	70	22.62	10/18/90	0115
	du6	42	9.08	70	19.13	10/18/90	0140
	du7	42	9.65	70	15.63	10/18/90	0204
Provincetown	pr2	42	7.47	70	14.96	10/18/90	0242
Plymouth	pl7	42	5.23	70	14.18	10/18/90	0317
	pl6	42	4.12	70	17.34	10/18/18	0404
	pl5	42	2.45	70	20.78	10/18/90	0432
	pl4	42	1.89	70	23.87	10/18/90	0500
	pl3	42	.70	70	27.67	10/18/90	0542
	pl2	41	59.61	70	30.49	10/18/90	0604
	pl1	41	58.50	70	33.73	10/18/90	0629
South Ply.	sp2	41	56.42	70	31.97	10/18/90	0659
Manomet	ma1	41	54.32	70	30.12	10/18/90	0723
	ma2	41	54.91	70	25.96	10/18/90	0754
	ma3	41	55.52	70	21.89	10/18/90	0821
	ma4	41	55.94	70	17.96	10/18/90	0854
	ma5	41	56.47	70	13.82	10/18/90	0922
	ma6	41	56.99	70	9.68	10/18/90	0950
Wellfleet	we2	41	53.73	70	9.10	10/18/90	1025
	sw6	41	50.46	70	8.44	10/18/90	1056
	sw5	41	49.90	70	12.14	10/18/90	1129
	sw4	41	49.42	70	15.98	10/18/90	1159
	sw3	41	48.90	70	19.88	10/18/90	1226
	sw2	41	48.36	70	23.60	10/18/90	1258
	sw1	41	47.92	70	27.33	10/18/90	1323

Table H7: Station list for UMB hydrographic cruise on February 4–6, 1991.

Section	Station	Latitude		Longitude		Date	Time
Nahant	na1	42	22.29	70	54.93	2/4/91	1028
	na3	42	26.28	70	49.44	2/4/91	1144
	na4	42	28.35	70	46.68	2/4/91	1224
Rockport	ro1	42	36.56	70	36.02	2/4/91	1404
	ro2	42	36.83	70	32.62	2/4/91	1430
	ro3	42	37.15	70	29.24	2/4/91	1455
	ro4	42	37.80	70	22.42	2/4/91	1539
	ro5	42	38.46	70	15.65	2/4/91	1635
	ro6	42	39.08	70	8.87	2/4/91	1725
Gulf of Maine	gm2	42	36.10	70	6.89	2/4/91	1830
	gm3	42	33.14	70	3.89	2/4/91	1905
	gm4	42	30.19	70	1.44	2/4/91	1956
	gm5	42	27.19	69	58.91	2/4/91	2034
Boston Extended	be4	42	26.62	70	5.94	2/4/91	2223
	be3	42	25.91	70	12.64	2/4/91	2306
	be2	42	25.26	70	19.55	2/4/91	2359
	be1	42	24.62	70	26.43	2/5/91	0045
Cape Ann	ca5	42	27.72	70	28.82	2/5/91	0139
	ca4	42	29.86	70	30.71	2/5/91	0209
	ca3	42	31.99	70	32.46	2/5/91	0249
	ca2	42	34.24	70	34.26	2/5/91	0319
	ca1	42	36.55	70	35.98	2/5/91	0359
Gloucester	gl2	42	34.88	70	38.42	2/5/91	0431
	gl1	42	32.82	70	41.23	2/5/91	0459
Salem	sa1	42	30.75	70	43.83	2/5/91	0525
	sa2	42	29.46	70	40.31	2/5/91	0604
	sa3	42	28.23	70	36.78	2/5/91	0632
	sa4	42	27.02	70	33.07	2/5/91	0715
	sa5	42	25.85	70	29.56	2/5/91	0740
Boston	bo8/sc6	42	24.65	70	26.40	2/5/91	0806
	bo7	42	24.25	70	30.38	2/5/91	0844
	bo6	42	23.99	70	34.27	2/5/91	0916
	bo5	42	23.58	70	38.60	2/5/91	1012
	bo4	42	23.24	70	42.69	2/5/91	1044
	bo3	42	22.89	70	46.71	2/5/91	1111
	bo2	42	22.52	70	50.78	2/5/91	1155
	bo1	42	22.19	70	54.90	2/5/91	1221
Cohasset	co2	42	20.69	70	50.15	2/5/91	1315
	co3	42	19.21	70	45.42	2/5/91	1351
	co4	42	17.68	70	40.62	2/5/91	1428

Table H7 (Con't): Station list for cruise on February 4-6, 1991

Section	Station	Latitude		Longitude		Date	Time
Scituate	sc1	42	11.93	70	39.98	2/5/91	1525
	sc2	42	13.73	70	36.33	2/5/91	1600
	sc3	42	15.21	70	32.52	2/5/91	1623
	sc4	42	17.20	70	29.04	2/5/91	1657
	sc5	42	19.05	70	25.34	2/5/91	1738
	sc6	42	20.75	70	21.83	2/5/91	1810
	sc6	42	21.59	70	20.24	2/5/91	1845
	sc7	42	22.65	70	18.06	2/5/91	1902
	sc8	42	24.45	70	14.41	2/5/91	1937
	sc9	42	23.70	70	8.06	2/5/91	2015
	sc10/hu9	42	22.92	70	1.65	2/5/91	2056
Humarock	hu9	42	20.95	70	6.71	2/5/91	2150
	hu8	42	18.95	70	11.84	2/5/91	2230
	hu7	42	17.01	70	16.95	2/5/91	2259
	hu6	42	15.71	70	20.44	2/5/91	2335
	hu5	42	14.23	70	24.02	2/6/91	0002
	hu4	42	12.43	70	27.61	2/6/91	0033
	hu3	42	11.71	70	31.08	2/6/91	0112
	hu2	42	10.27	70	34.50	2/6/91	0140
	hu1	42	8.84	70	38.07	2/6/91	0209
Duxbury	du1	42	5.74	70	36.02	2/6/91	0246
	du2	42	6.45	70	32.84	2/6/91	0319
	du3	42	6.99	70	29.69	2/6/91	0345
	du4	42	7.79	70	26.31	2/6/91	0409
	du5	42	8.29	70	22.64	2/6/91	0449
	du6	42	9.09	70	19.10	2/6/91	0515
	du7	42	9.65	70	15.62	2/6/91	0538
	du8	42	10.45	70	11.54	2/6/91	0612
	du9	42	11.27	70	7.48	2/6/91	0640
	du10	42	12.08	70	3.31	2/6/91	0708
	du11	42	10.24	70	1.68	2/6/91	0746
Highlands	hi5	42	8.53	69	59.98	2/6/91	0813
	hi4	42	6.52	70	1.63	2/6/91	0903
	hi3	42	4.47	70	3.44	2/6/91	0924
	hl2	42	6.00	70	6.32	2/6/91	1001
	hi1	42	6.42	70	9.88	2/6/91	1028
Plymouth	pl7	42	5.22	70	14.08	2/6/91	1100
	pl6	42	4.10	70	17.31	2/6/91	1138
	pl5	42	3.01	70	20.73	2/6/91	1204
	pl4	42	1.92	70	23.85	2/6/91	1218
	pl3	42	.70	70	27.67	2/6/91	1309
	pl2	41	59.66	70	30.43	2/6/91	1339
	pl1	41	58.50	70	33.69	2/6/91	1402

Table H7 (Con't): Station list for cruise on February 4-6, 1991

Section	Station	Latitude		Longitude		Date	Time
South Ply.	sp2	41	56.44	70	31.86	2/6/91	1430
Manomet	ma1	41	54.32	70	30.04	2/6/91	1455
	ma2	41	54.92	70	25.92	2/6/91	1533
	ma3	41	55.47	70	21.87	2/6/91	1601
	ma4	41	55.94	70	17.96	2/6/91	1634
	ma5	41	56.51	70	13.77	2/6/91	1701
	ma6	41	56.99	70	9.72	2/6/91	1727
Wellfleet	we2	41	53.69	70	9.19	2/6/91	1806
Sandwich	SW6	41	50.47	70	8.46	2/6/91	1844
	sw5	41	49.97	70	12.14	2/6/91	1910
	sw4	41	49.39	70	15.98	2/6/91	1932
	sw3	41	48.80	70	19.90	2/6/91	2000
	sw2	41	48.46	70	23.61	2/6/91	1029
	sw1	41	48.03	70	27.28	2/6/91	2055

Table H8: Station list for UMB hydrographic cruise on March 20–23, 1991

Section	Station	Latitude		Longitude		Date	Time
Nahant	na1	42	22.17	70	54.80	3/20/91	2320
	na2	42	24.07	70	52.28	3/20/91	2345
	na3	42	26.30	70	49.38	3/21/91	0015
	na4	42	28.39	70	46.68	3/21/91	0055
	na5	42	30.69	70	43.89	3/21/91	0128
Rockport	ro1	42	36.57	70	36.01	3/21/91	0228
	ro2	42	36.82	70	32.58	3/21/91	0258
	ro3	42	37.15	70	29.21	3/21/91	0318
	ro4	42	37.73	70	22.35	3/21/91	0409
	ro5	42	38.35	70	15.61	3/21/91	0505
	ro6/gm1	42	39.01	70	8.85	3/21/91	0548
Gulf of Maine	gm2	42	36.01	70	6.35	3/21/91	0634
	gm3	42	33.05	70	3.90	3/21/91	0708
	gm4	42	30.21	70	1.37	3/21/91	0802
	be5/gm5	42	27.24	69	58.83	3/21/91	0903
Boston Extended	be4	42	26.61	70	5.91	3/21/91	0952
	be3	42	25.95	70	12.71	3/21/91	1033
	be2	42	25.19	70	19.60	3/21/91	1126
Cape Ann	ca6/be1	42	24.58	70	26.43	3/21/91	1208
	ca5	42	27.60	70	28.78	3/21/91	1255
	ca4	42	29.85	70	30.67	3/21/91	1319
	ca3	42	31.97	70	32.51	3/21/91	1358
	ca2	42	34.29	70	34.30	3/21/91	1422
	ca1	42	36.55	70	36.09	3/21/91	1459
Gloucester	gl2	42	34.87	70	38.38	3/21/91	1530
	gl1	42	32.81	70	41.31	3/21/91	1555
Salem	sa1	42	30.72	70	43.93	3/21/91	1621
	sa2	42	29.47	70	40.37	3/21/91	1656
	sa3	42	28.23	70	36.80	3/21/91	1725
	sa4	42	27.02	70	33.07	3/21/91	1806
	sa5	42	25.90	70	29.61	3/21/91	1832
Boston	bo8/sa6	42	24.60	70	26.48	3/21/91	1910
	bo7	42	24.29	70	30.56	3/21/91	1945
	bo6	42	23.93	70	34.58	3/21/91	2015
	bo5	42	23.60	70	38.67	3/21/91	2059
	bo4	42	23.30	70	42.68	3/21/91	2128
	bo3	42	22.90	70	46.74	3/21/91	2157
	bo2	42	22.55	70	50.85	3/21/91	2238
	bo1/co1	42	22.35	70	54.94	3/21/91	2305

Table H8 (Con't): Station list for cruise on March 20–23, 1991

Section	Station	Latitude		Longitude		Date	Time
Cohasset	co2	42	20.63	70	50.10	3/21/91	2355
	co3	42	19.19	70	45.38	3/22/91	0027
	co4	42	17.69	70	40.51	3/22/91	0102
Scituate	sc1/co5	42	11.87	70	39.94	3/22/91	0202
	sc2	42	13.72	70	36.36	3/22/91	0241
	sc3	42	15.46	70	32.74	3/22/91	0313
	sc4	42	17.24	70	29.09	3/22/91	0343
	sc5	42	19.00	70	25.49	3/22/91	0430
	sc6	42	20.80	70	21.87	3/22/91	0522
	sc6A	42	21.50	70	20.26	3/22/91	0554
	sc7	42	22.62	70	18.22	3/22/91	0608
	sc8	42	24.44	70	14.60	3/22/91	0647
	sc9	42	23.68	70	8.13	3/22/91	0728
	sc10/hu1	42	22.84	70	1.66	3/22/91	0805
UNH U6 moor.	UNHSB	42	21.19	70	24.10	3/22/91	0500
Humarock	hu9	42	20.97	70	6.69	3/22/91	0900
	hu8	42	18.97	70	11.91	3/22/91	0947
	hu6	42	15.70	70	20.48	3/22/91	1101
	hu5	42	14.25	70	24.12	3/22/91	1128
	hu4	42	12.94	70	27.55	3/22/91	1203
	hu3	42	11.56	70	31.07	3/22/91	1231
	hu2	42	10.23	70	34.51	3/22/91	1257
	hu1	42	8.79	70	38.03	3/22/91	1326
Duxbury	du1	42	5.83	70	36.02	3/22/91	1403
	du2	42	6.45	70	32.88	3/22/91	1431
	du3	42	7.10	70	29.68	3/22/91	1455
	du4	42	7.79	70	26.31	3/22/91	1520
	du5	42	8.33	70	22.65	3/22/91	1601
	du6	42	9.06	70	19.18	3/22/91	1627
	du7	42	9.62	70	15.64	3/22/91	1651
	du8	42	10.42	70	11.52	3/22/91	1727
	du9	42	11.22	70	7.44	3/22/91	1751
	du10	42	12.02	70	3.39	3/22/91	1816
Highlands	hi5	42	8.52	69	59.98	3/22/91	1907
	hi4	42	6.43	70	1.69	3/22/91	1952
	hi3	42	4.48	70	3.54	3/22/91	2017
	hi2	42	6.04	70	6.34	3/22/91	2048
	hi1	42	6.37	70	9.95	3/22/91	2115

Table H8 (Con't): Station list for cruise on March 20–23, 1991

Section	Station	Latitude		Longitude		Date	Time
Provincetown	pr1	42	5.25	70	14.22	3/22/91	2143
(USGS moor.)	usgs	42	6.41	70	14.82	3/22/91	2208
	pr2	42	7.57	70	15.35	3/22/91	2225
Plymouth	pl6	42	4.06	70	17.41	3/22/91	2306
	pl5	42	2.91	70	20.37	3/22/91	2329
	pl4	42	1.89	70	23.85	3/22/91	2353
	pl3	42	.64	70	27.67	3/23/91	0029
	pl2	41	59.58	70	30.48	3/23/91	0052
	pl1	41	58.48	70	33.72	3/23/91	0115
South Ply.	sp2	41	56.37	70	31.94	3/23/91	0142
Manomet	ma1	41	54.29	70	30.06	3/23/91	0208
	ma2	41	54.87	70	25.99	3/23/91	0249
	ma3	41	55.49	70	21.90	3/23/91	0315
	ma4	41	55.97	70	18.01	3/23/91	0405
	ma5	41	56.47	70	13.86	3/23/91	0435
	ma6	41	56.97	70	9.73	3/23/91	0504
UNH CCB moor	UNHCCB	41	57.02	70	19.95	3/23/91	0345
Wellfleet	we2	41	53.73	70	9.20	3/23/91	0538
Sandwich	sw6	41	50.47	70	8.46	3/23/91	0608
	sw5	41	49.99	70	12.20	3/23/91	0630
	sw4	41	49.40	70	15.99	3/23/91	0655
	sw3	41	48.93	70	19.87	3/23/91	0716
	sw2	41	48.41	70	23.61	3/23/91	0744
	sw1	41	47.92	70	27.31	3/23/91	0809

Table H9: Station list for UMB hydrographic cruise on March 25–26, 1991

Section	Station	Latitude		Longitude		Date	Time
Boston	bo1	42	22.35	70	54.94	3/25/91	1152
	bo2	42	22.55	70	50.85	3/25/91	1214
	bo3	42	22.90	70	46.74	3/25/91	1240
	bo4	42	23.30	70	42.68	3/25/91	1320
	bo5	42	23.60	70	38.67	3/25/91	1347
	bo6	42	23.93	70	34.58	3/25/91	1415
	bo7	42	24.29	70	30.56	3/25/91	1446
	bo8/ca6	42	24.60	70	26.48	3/25/91	1519
Cape Ann	ca5	42	27.60	70	28.78	3/25/91	1549
	ca4	42	29.85	70	30.67	3/25/91	1614
	ca3	42	31.97	70	32.51	3/25/91	1642
	ca2	42	34.29	70	34.30	3/25/91	1709
	ca1/ro1	42	36.55	70	36.09	3/25/91	1736
Rockport	ro3	42	37.15	70	29.21	3/25/91	1829
	ro4	42	37.73	70	22.35	3/25/91	1912
	ro5	42	38.35	70	15.61	3/25/91	1958
	ro6/gm2	42	39.01	70	8.85	3/25/91	2041
Gulf of Maine	gm2	42	36.01	70	6.35	3/25/91	2115
	gm3	42	33.05	70	3.90	3/25/91	2156
	gm4	42	30.21	70	1.37	3/25/91	2224
	gm5	42	27.24	69	58.83	3/25/91	2300
	hu10	42	22.84	70	1.66	3/25/91	2346
	hu/du	42	17.45	70	2.39	3/26/91	0032
	du10	42	12.02	70	3.39	3/26/91	0118
Highlands	hi5	42	8.52	69	59.98	3/26/91	0157
	hi4	42	6.43	70	1.69	3/26/91	0226
	hi3	42	4.48	70	3.54	3/26/91	0249
	hi2	42	6.04	70	6.27	3/26/91	0315
	hi1	42	6.37	70	9.95	3/26/91	0343
Provincetown (USGS moor.)	pr1	42	5.25	70	14.22	3/26/91	0409
	bb	42	6.41	70	14.82	3/26/91	0427
	pr2	42	7.57	70	15.35	3/26/91	0445
Plymouth	pl6	42	4.12	70	17.37	3/26/91	2306
	pl5	42	2.91	70	20.87	3/26/91	0545
	pl4	42	1.89	70	23.85	3/26/91	0613
	pl3	42	.64	70	27.67	3/26/91	0637
	pl2	41	59.58	70	30.48	3/23/91	0052
	pl1	41	58.48	70	33.72	3/26/91	0720

Table H9 (Con't): Station list for UMB hydrographic cruise on March 25–26, 1991

Section	Station	Latitude	Longitude	Date	Time
Coastal	pl/du	42 2.17	70 34.89	3/26/91	0753
	du1	42 5.83	70 36.02	3/26/91	0830
	hu1	42 8.79	70 38.03	3/26/91	0859
	co5	42 11.87	70 39.94	3/26/91	0929
	co4	42 17.69	70 40.51	3/26/91	1013
	co3	42 19.19	70 45.38	3/26/91	1045
	co2	42 20.63	70 50.10	3/26/91	1118
	co1	42 22.35	70 54.94	3/26/91	1152

Table H10: Station list for UMB hydrographic cruise on April 29–May 2, 1991

Section	Station	Latitude		Longitude		Date	Time
Nahant	na1	42	22.19	70	54.82	4/29/91	1251
	na2	42	24.07	70	52.24	4/29/91	1319
	na3	42	26.27	70	49.27	4/29/91	1348
	na4	42	28.47	70	46.70	4/29/91	1424
	na5	42	30.71	70	43.90	4/29/91	1451
Rockport	ro1	42	36.61	70	36.13	4/29/91	1553
	ro2	42	36.89	70	32.66	4/29/91	1621
	ro3	42	37.10	70	29.27	4/29/91	1644
	ro4	42	37.81	70	22.46	4/29/91	1728
	ro5	42	38.48	70	15.65	4/29/91	1817
	ro6/gm1	42	39.13	70	8.87	4/29/91	1901
Gulf of Maine	gm2	42	36.18	70	6.44	4/29/91	1955
	gm3	42	33.16	70	3.88	4/29/91	2036
	gm4	42	30.21	70	1.45	4/29/91	2128
	be6/gm1	42	27.24	69	58.91	4/29/91	2315
Boston Extended	be4	42	26.58	70	5.75	4/30/91	0003
	be3	42	25.90	70	12.66	4/30/91	0050
	be2	42	25.27	70	19.56	4/30/91	0208
Cape Ann	ca6/be1	42	24.58	70	26.43	4/30/91	0252
	ca5	42	27.66	70	28.82	4/30/91	0338
	ca4	42	29.86	70	30.72	4/30/91	0404
	ca3	42	32.09	70	32.33	4/30/91	0446
	ca2	42	34.32	70	34.27	4/30/91	0510
	ca1	42	36.47	70	35.92	4/30/91	0545
Gloucester	gl2	42	34.90	70	38.47	4/30/91	0615
	gl1	42	32.87	70	41.29	4/30/91	0643
Salem	sa1	42	30.76	70	43.89	4/30/91	0708
	sa2	42	29.52	70	40.36	4/30/91	0742
	sa3	42	28.17	70	36.58	4/30/91	0811
	sa4	42	27.02	70	33.18	4/30/91	0853
	sa5	42	25.78	70	29.45	4/30/91	0921
Boston	bo8/sa6	42	24.56	70	26.51	4/30/91	0921
	bo7	42	24.24	70	30.51	4/30/91	1020
	bo6	42	23.91	70	34.66	4/30/91	1043
	bo5	42	23.51	70	38.72	4/30/91	1123
	bo4	42	23.22	70	42.71	4/30/91	1150
	bo3	42	22.87	70	46.77	4/30/91	1222
	bo2	42	22.62	70	51.01	4/30/91	1255
	bo1/co1	42	22.15	70	54.86	4/30/91	1322

Table H10 (Con't): Station list for cruise on April 29–May 2, 1991

Section	Station	Latitude		Longitude		Date	Time
Cohasset	co2	42	20.69	70	50.19	4/30/91	1410
	co3	42	19.23	70	45.40	4/30/91	1445
	co4	42	17.73	70	40.63	4/30/91	1520
Scituate	sc1	42	11.98	70	39.96	4/30/91	1617
	sc2	42	13.73	70	36.35	4/30/91	1650
	sc3	42	15.51	70	32.75	4/30/91	1719
	sc4	42	17.28	70	29.16	4/30/91	1749
	sc5	42	19.06	70	25.55	4/30/91	1833
	sc6	42	20.91	70	22.01	4/30/91	1923
	sc6	42	21.54	70	20.34	4/30/91	2000
	sc7	42	22.65	70	18.29	4/30/91	2022
	sc8	42	24.51	70	14.55	4/30/91	2358
	sc9	42	23.74	70	8.07	5/1/91	0041
	sc10/hu1	42	22.94	70	1.57	5/1/91	0123
UNH U6 moor.	UNHSB	42	21.41	70	24.14	4/30/91	1856
Humarock	hu9	42	20.95	70	6.67	5/1/91	0230
	hu8	42	18.97	70	11.70	5/1/91	0313
	hu7	42	17.01	70	16.80	5/1/91	0354
	hu6	42	15.66	70	20.37	5/1/91	0435
	hu5	42	14.23	70	24.01	5/1/91	0504
	hu4	42	12.82	70	27.43	5/1/91	0532
	hu3	42	11.53	70	31.04	5/1/91	0610
	hu2	42	10.32	70	34.49	5/1/91	0635
	hu1	42	8.84	70	38.02	5/1/91	0700
Duxbury	du1	42	5.84	70	36.08	5/1/91	0737
	du2	42	6.44	70	32.88	5/1/91	0802
	du3	42	7.09	70	29.67	5/1/91	0825
	du4	42	7.75	70	26.28	5/1/91	0851
	du5	42	8.24	70	22.71	5/1/91	0935
	du6	42	9.06	70	19.22	5/1/91	1001
	du7	42	9.67	70	15.79	5/1/91	1029
	du8	42	10.44	70	11.61	5/1/91	1106
	du9	42	11.21	70	7.51	5/1/91	1138
	du10	42	12.05	70	3.37	5/1/91	1208
Highlands	hi5	42	8.48	70	.01	5/1/91	1303
	hi4	42	6.46	70	1.77	5/1/91	1352
	hi3	42	4.45	70	3.52	5/1/91	1425
	hi2	42	5.98	70	6.34	5/1/91	1459
	hi1	42	6.38	70	9.96	5/1/91	1530

Table H10 (Con't): Station list for cruise on April 29–May 2, 1991

Section	Station	Latitude		Longitude		Date	Time
Provincetown	pr1	42	5.25	70	14.22	5/1/91	1403
	pr2	42	7.59	70	15.36	5/1/91	1644
Plymouth	pl6	42	4.17	70	17.41	5/1/91	1732
	pl5	42	2.91	70	20.87	5/1/91	1758
	pl4	42	1.92	70	23.87	5/1/91	1822
	pl3	42	.71	70	27.73	5/1/91	1906
	pl2	41	59.61	70	30.43	5/1/91	1933
	pl1	41	58.47	70	33.71	5/1/91	2001
South Plym.	sp2	41	56.46	70	31.61	5/1/91	2027
Manomet	ma1	41	54.31	70	29.99	5/1/91	2050
	ma2	41	54.83	70	25.92	5/1/91	2124
	ma3	41	55.47	70	21.92	5/1/91	2224
	ma4	41	55.95	70	17.96	5/1/91	2307
	ma5	41	56.40	70	13.88	5/1/91	2335
	ma6	41	57.01	70	9.70	5/2/91	0014
UNH CCB moor	UNHCCB	41	57.08	70	20.00	5/1/91	2245
Wellfleet	we2	41	53.72	70	9.10	5/2/91	0049
Sandwich	sw6	41	50.47	70	8.60	5/2/91	0126
	sw5	41	50.01	70	12.10	5/2/91	0154
	sw4	41	49.43	70	15.98	5/2/91	0219
	sw3	41	48.89	70	19.86	5/2/91	0247
	sw2	41	48.34	70	23.64	5/2/91	0320
	sw1	41	47.92	70	27.39	5/2/91	0345

Table H11: Station list for UMB hydrographic cruise on May 4–5, 1991

Section	Station	Latitude		Longitude		Date	Time
Boston	bo1	42	22.09	70	54.70	5/4/91	1628
	bo2	42	22.53	70	50.82	5/4/91	1659
	bo3	42	22.86	70	46.65	5/4/91	1724
	bo4	42	23.72	70	42.70	5/4/91	1758
	bo5	42	23.50	70	38.65	5/4/91	1823
	bo6	42	23.83	70	34.57	5/4/91	1850
	bo7	42	24.21	70	30.44	5/4/91	1922
	bo8/ca6	42	24.54	70	26.37	5/4/91	1950
Cape Ann	ca5	42	27.58	70	28.76	5/4/91	2021
	ca4	42	29.95	70	30.68	5/4/91	2051
	ca3	42	31.92	70	32.56	5/4/91	2130
	ca2	42	34.16	70	34.30	5/4/91	2159
	ca1/ro1	42	36.49	70	35.89	5/4/91	2232
Rockport	ro2	42	36.81	70	32.65	5/4/91	2255
	ro3	42	37.10	70	29.27	5/4/91	2321
	ro4	42	37.78	70	22.51	5/5/91	0007
	ro5	42	38.41	70	15.71	5/5/91	0057
	ro6/gm1	42	39.06	70	8.87	5/5/91	0142
Gulf of Maine	gm2	42	36.10	70	6.40	5/5/91	0216
	gm3	42	33.11	70	3.87	5/5/91	0250
	gm4	42	30.13	70	1.39	5/5/91	0328
	gm5	42	27.20	69	58.85	5/5/91	0402
	hu10	42	22.89	70	1.57	5/5/91	0446
	hu/du	42	17.45	70	2.39	5/5/91	0527
	du10	42	12.07	70	3.28	5/5/91	0611
Highlands	hi5	42	8.49	69	59.87	5/5/91	0065
	hi4	42	6.46	70	1.57	5/5/91	0716
	hi3	42	4.50	70	3.46	5/5/91	0742
	hi2	42	5.98	70	6.27	5/5/91	0807
	hi1	42	6.41	70	9.83	5/5/91	0835
Provincetown (USGS moor.)	pr1	42	5.30	70	14.14	5/5/91	0907
	usgs	42	6.39	70	14.54	5/5/91	0922
	pr2	42	7.61	70	15.30	5/5/91	0940
Plymouth	pl6	42	4.21	70	17.38	5/5/91	1014
	pl5	42	2.89	70	20.81	5/5/91	1038
	pl4	42	1.82	70	23.89	5/5/91	1100
	pl3	42	.62	70	27.71	5/5/91	1145
	pl2	41	59.54	70	30.49	5/5/91	1207
	pl1	41	58.45	70	33.74	5/5/91	1232

Table H11 (Con't): Station list for cruise on May 4–5, 1991

Section	Station	Latitude		Longitude		Date	Time
Coastal	pl/du	42	2.17	70	34.89	5/5/91	1305
	dul	42	5.80	70	36.06	5/5/91	1335
	hul	42	8.84	70	38.02	5/5/91	1405
	co4	42	17.73	70	40.66	5/5/91	1515
	co3	42	19.22	70	45.41	5/5/91	1545
	co2	42	20.75	70	50.13	5/5/91	1615
	col	42	22.17	70	54.90	5/5/91	1645

Table H12: Station list for UMB hydrographic cruise on June 18, 1991.

Section	Station	Latitude		Longitude		Date	Time
Boston	bo1	42	22.04	70	55.05	6/18/91	1735
	bo2	42	22.54	70	51.64	6/18/91	0937
	bo3	42	22.54	70	47.07	6/18/91	0955
	bo4	42	23.12	70	42.69	6/18/91	1032
	bo5	42	23.42	70	38.48	6/18/91	1052
	bo6	42	23.85	70	34.30	6/18/91	1113
	bo7	42	24.18	70	30.30	6/18/91	1207
	bo8/ca6	42	24.55	70	26.30	6/18/91	1240
	ca5	42	27.59	70	28.99	6/18/91	1323
	ca4	42	29.98	70	30.77	6/18/91	1343
	ca3	42	31.93	70	32.40	6/18/91	1416
	ca2	42	34.36	70	34.30	6/18/91	1437
	ca1	42	36.59	70	36.11	6/18/91	1509
Salem	sa3	42	28.22	70	37.03	6/18/91	1601
	sa2	42	29.49	70	40.52	6/18/91	1635
	sa1	42	30.73	70	44.30	6/18/91	1654

Appendix P: Wind Forced Pressure Variations

The statistical analysis of the Bays pressure field described below focuses on late autumn-early winter period of 26 October 1990 through 14 January 1991 when there was particularly detailed coverage of the Bays pressure field. This is a time when density stratification is very weak (see fig. 2.2-7) and the wind-forced response of the Bays was stronger than at other times in the year. (A linear trend has been removed from all pressure records during this time period.)

While difficult to discern in the series, the amplitude of the subtidal pressure fluctuations time intensified to the west and north of the Bays–consistent with Gulf of Maine-wide patterns. We use empirical orthogonal functions (EOFs) to describe the pattern of correlated pressure fluctuations at different observation points. Based on the strong visual similarity of the records, it is not surprising that the primary time-domain EOF (fig. P-1) explains 94.6% of the total pressure variance. In this case, sea level in the western Gulf of Maine–including the Bays–is heaving up and down with an amplitude of about 10 cm. An amplitude time series, which describes the temporal variation of the mode, looks very much like the pressure time series themselves. The primary pressure EOF is highly correlated (0.79) with the Bays NDBC buoy across-Bays windstress (fig. P-2). This is significant because it has been shown that the Gulf of Maine pressure field is clearly more strongly coupled to the across-Bays (i.e., along-Gulf) component of the wind stress than to the other windstress component. Thus we find that the Bays pressure field variability is an integral part of the larger scale Gulf of Maine response to a windstress.

In an effort to determine if the pressure response to winds is the same at all fluctuation periods, a frequency-domain statistical analysis was performed. Representative energy spectra (fig. P-3) show a concentration of the pressure variability energy in the 5- to 20-day period range–typical of wind-forced variability. The results of a frequency-domain EOF analysis of the pressures was consistent with the time-domain EOF analysis results but with slightly higher wind stress/pressure EOF coherence in the 20- and 5-daybands than at other frequencies.

The spatial structure of the Bays pressure difference variability provides an indication of the Bays-scale flow variability because subtidal ocean currents tend to be quasi-geostrophic and thus are related to pressure gradients perpendicular to the flow. The selected set of pressure difference time series (fig. P-4) have been subjected to a statistical analysis similar to that of the pressures. As expected the more widely separated station pairs tend to have the larger amplitude pressure difference signals. There are clearly greater differences among the pressure difference records than among the pressures themselves–reflecting the Bays-scale current variability. The spectra in figure P-3 show that the more energetic pressure difference (i.e., geostrophic flow) variability is in the 2- to 5-day period range.

A time-domain EOF analysis shows that nearly 90% of the pressure difference variance is explained by the first and second EOF modes (57.7%, 29.2%). The first EOF mode inflow/outflow pattern (fig. P-5) involves more of the Bays than the second EOF mode which appears to be localized around Stellwagen Bank. The first EOF mode is more highly correlated (0.70) with local wind stress than the second EOF mode (0.45). Therefore, about 36% of the geostrophic flow variance is wind-forced–a result similar to that derived from an EOF analysis of measured currents.

The primary time-domain EOF is most similar to the primary 5-day frequency domain EOF (fig. P-6) — consistent with the fluctuation energy concentration at those periods. The second time-domain EOF is most similar to the lower energy primary 20-day frequency-domain frequency domain EOF. The 20-day EOF, however, is not coherent with the wind. Thus the relationship between the two different EOF perspectives and the ocean variability they represent remains unresolved.

In summary, a statistical analysis of the Bays Program pressure field reveals a highly coherent inflow/outflow pattern response probably forced by winds. At this stage we have not partitioned the response between local and remote windstress forcing.

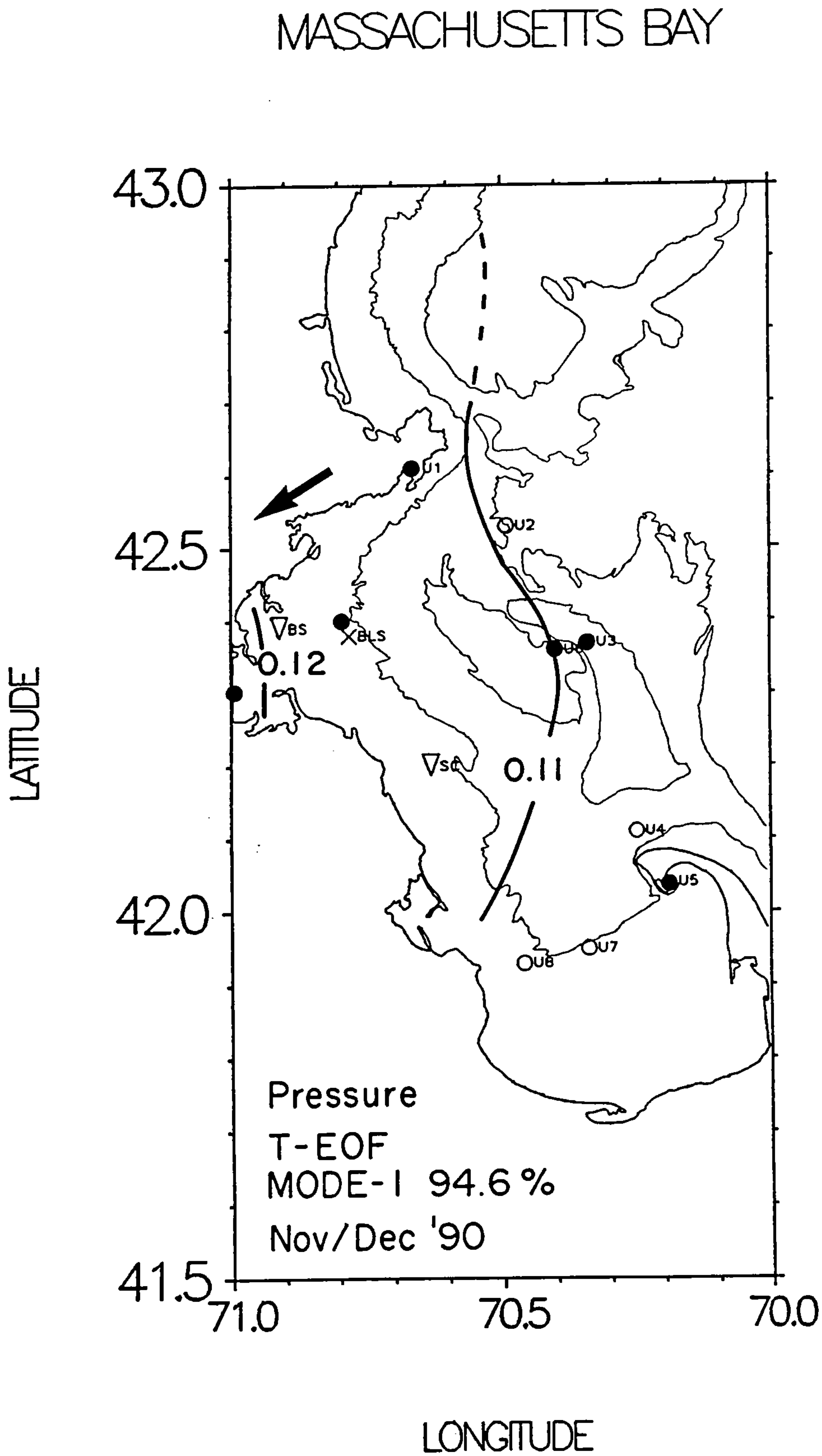


Figure P-1 Primary pressure empirical orthogonal function. Amplitudes in decibars. The arrow indicates the direction of the windstress (236°T) which is most highly correlated (0.86) with this mode.

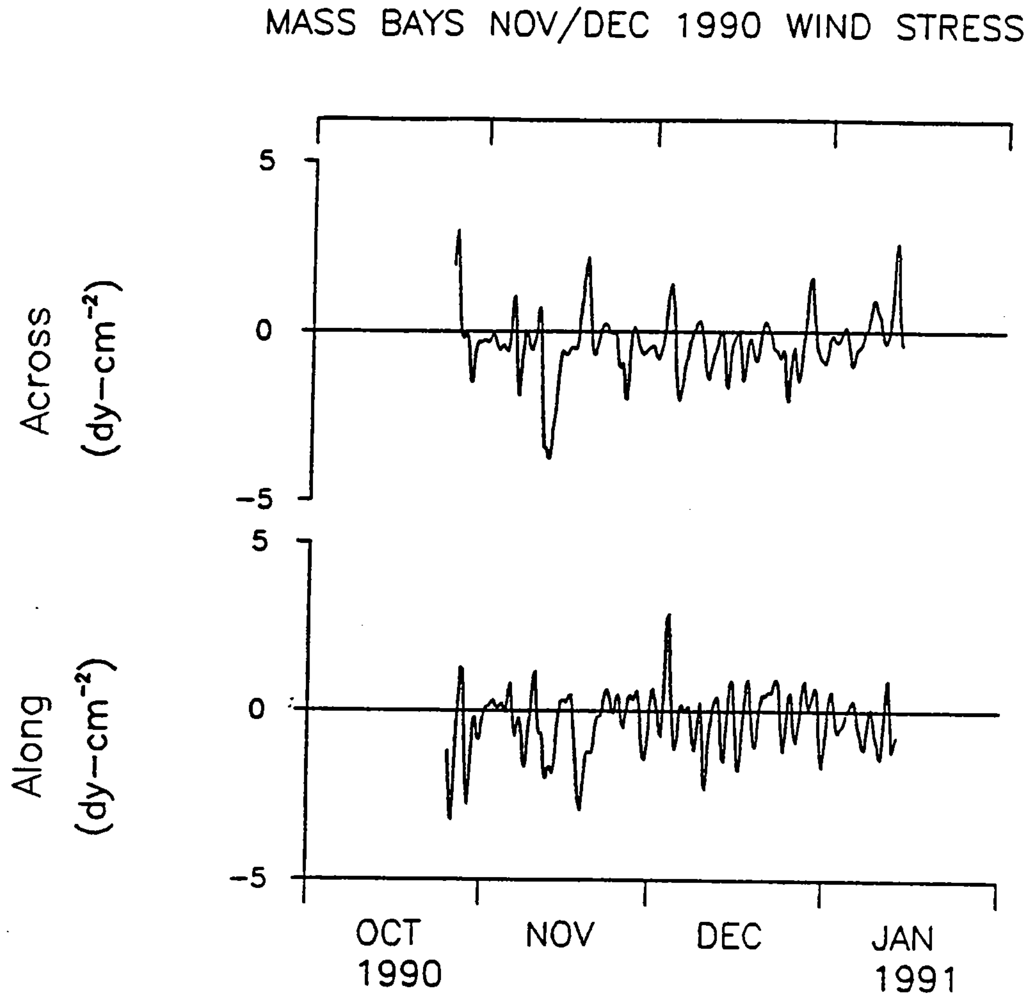


Figure P-2 The along-Bays (333°T) wind stress and the across-Bays (243°T) wind stress time series.

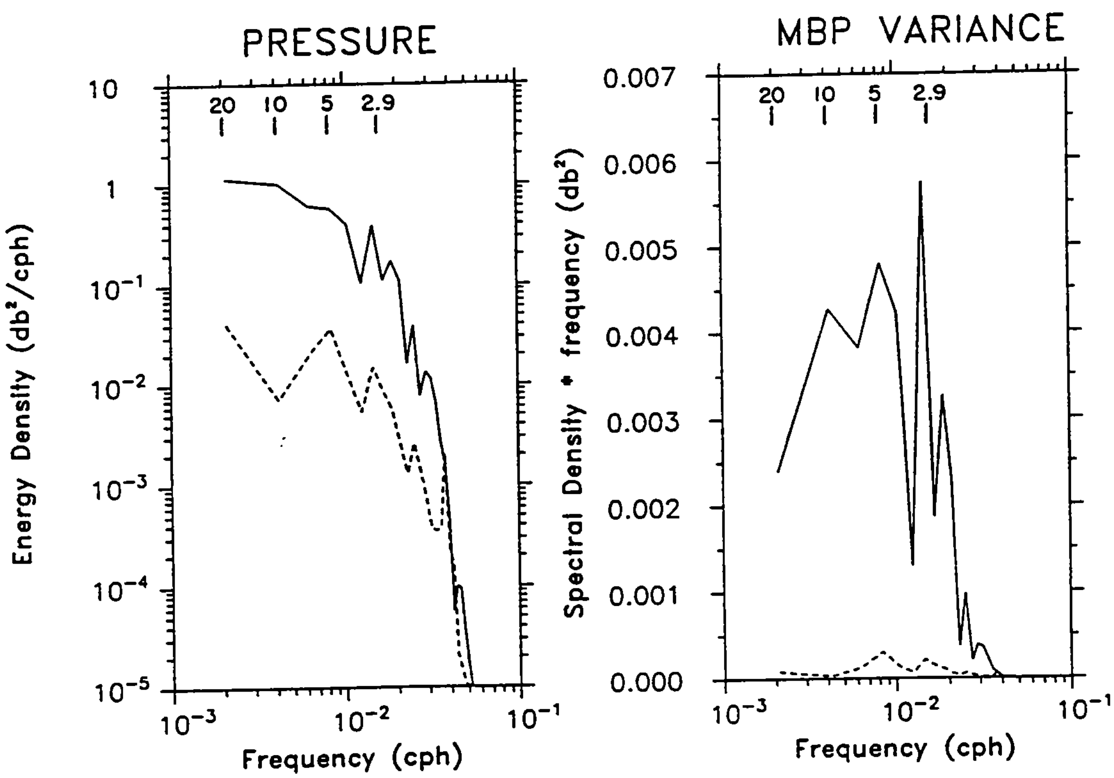


Figure P-3 Representative energy spectra of the Stellwagen Basin (U6) bottom pressure (solid) and the Boston SSP minus Stellwagen bottom pressure (dashed). (a) Energy density (b) Variance-preserving spectra. Selected fluctuation periods (in days) are indicated.

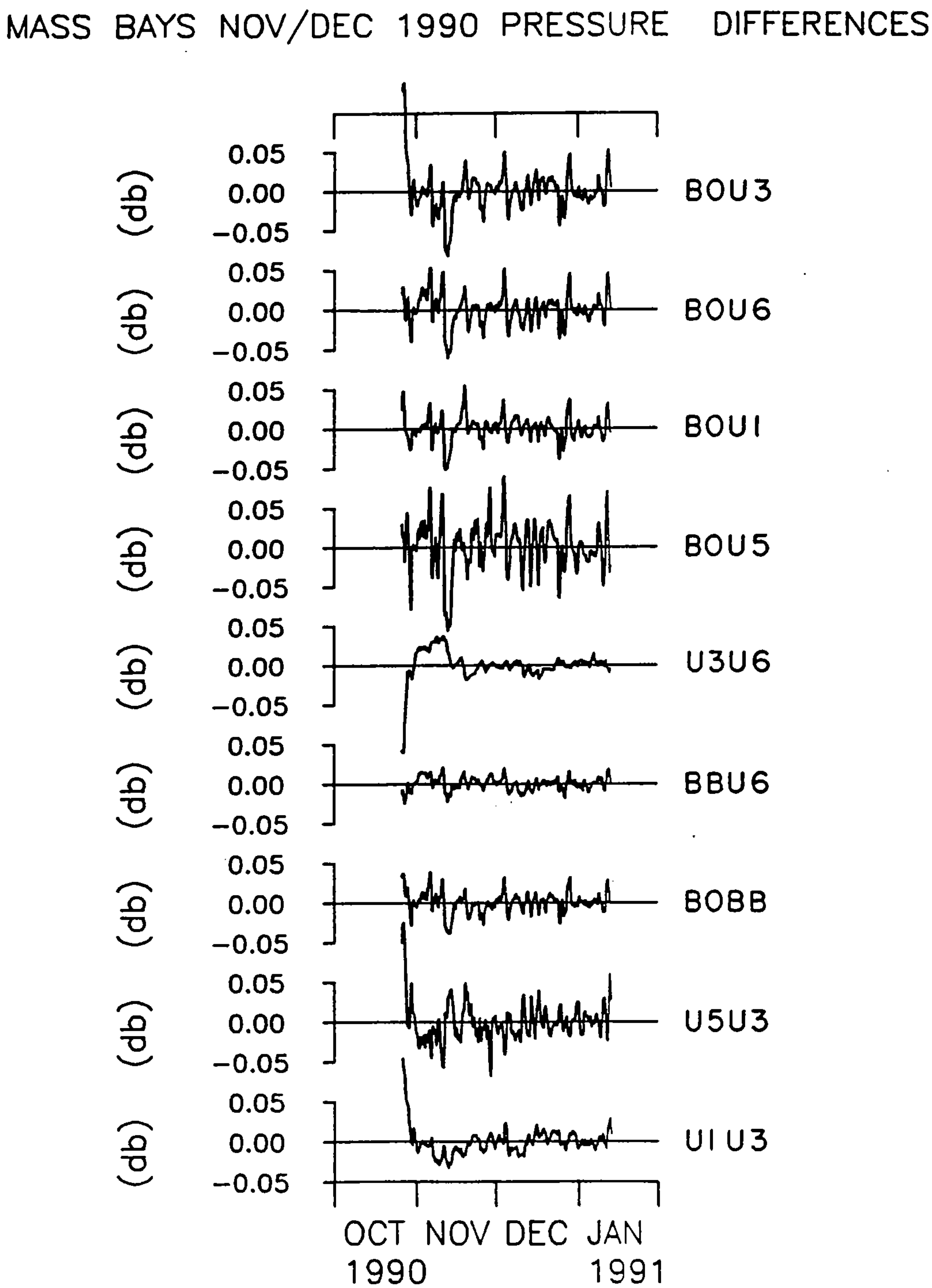
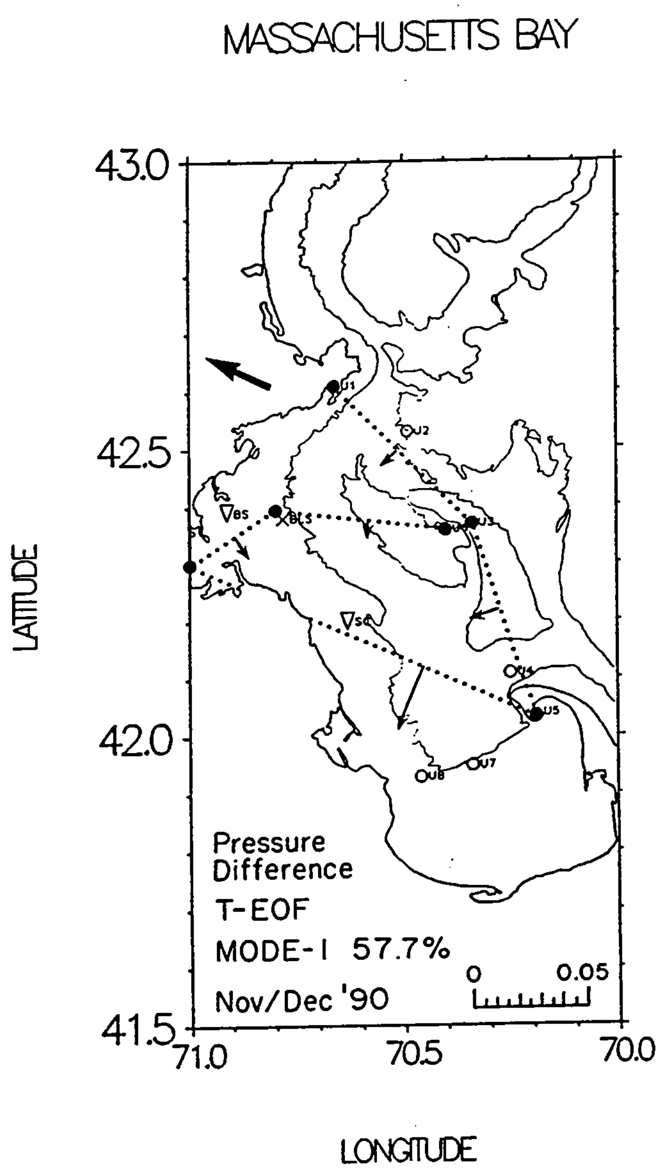


Figure P-4 Pressure differences between the indicated station pairs. A linear trend has been removed from each record.



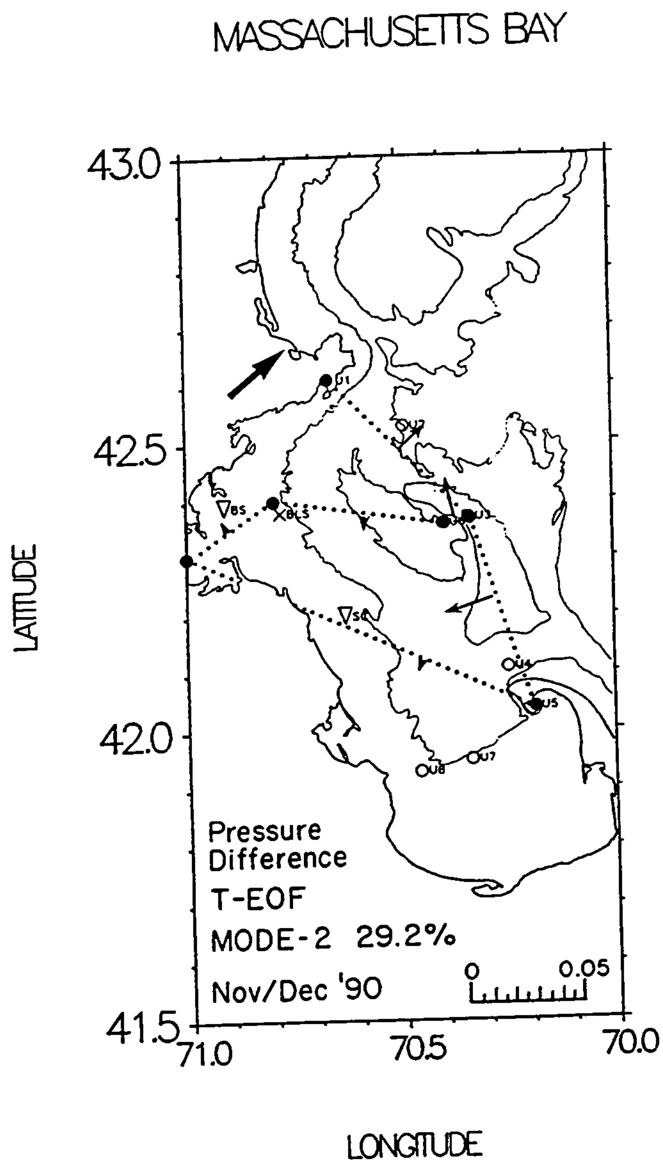


Figure P-5 First and second pressure difference EOFs. The amplitudes (mb) of the pressure differences are presented so as to suggest the magnitude and sense of the inferred geostrophic transport. The arrows on land indicate the direction of the windstress (mode-1, 296°T; mode-2, 41°T) most highly correlated with mode-1 (0.91) and mode-2 (0.60) respectively.

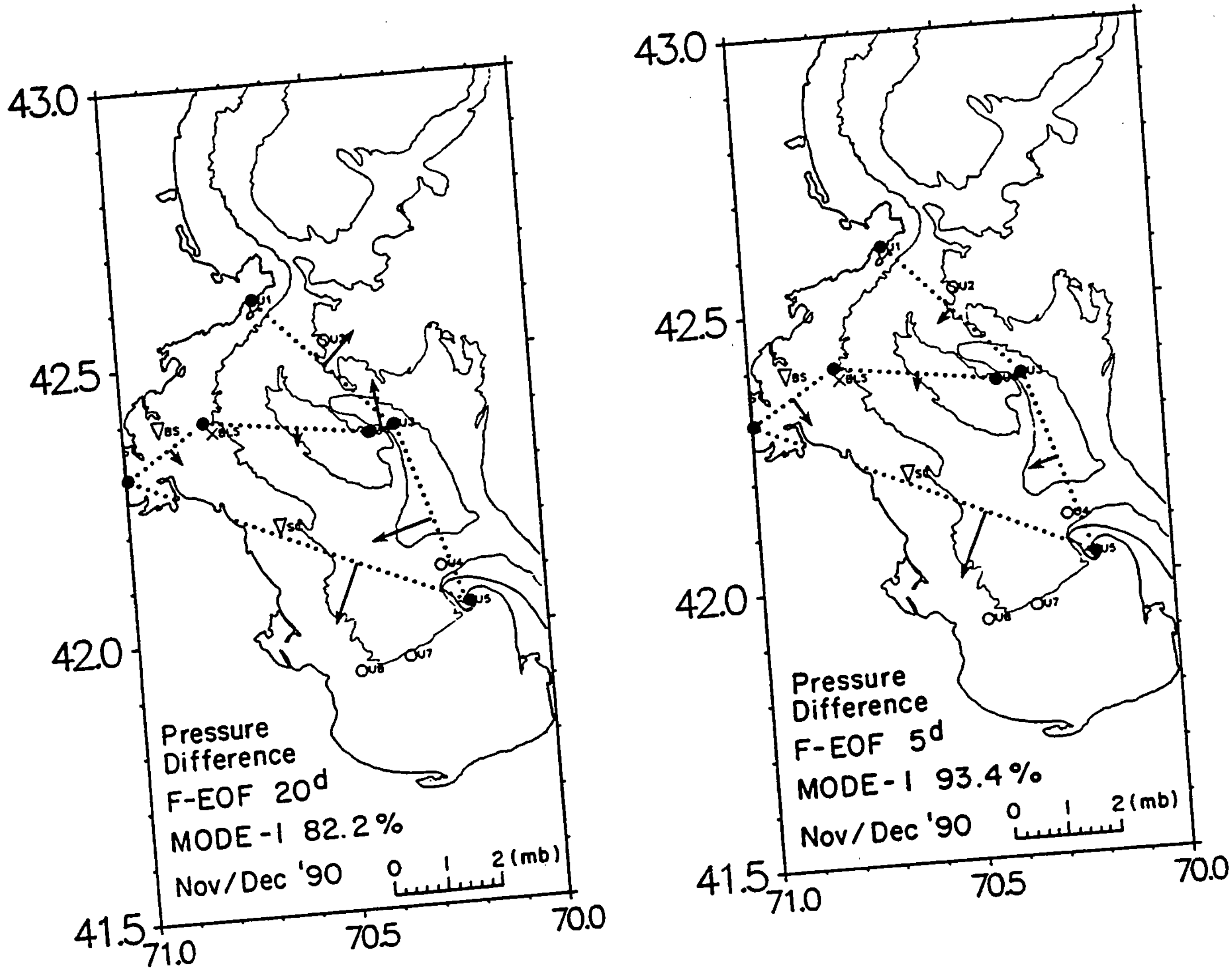


Figure P-6 The 20- and 5-day primary frequency-domain pressure difference EOFs. The amplitudes (mb) of the pressure differences are presented so as to suggest the magnitude and sense of the inferred geostrophic transport.

Appendix T: Tidal Analysis

Surface Elevation

For the Mass Bays experiment, the tidal elevation was measured by several bottom pressure instruments as well as coastal sea level at sites shown in figure T1. The bottom pressure and current records taken on Stellwagen Bank were chosen as a representative record of the tide forcing of Massachusetts Bays. Figure T2 shows power density spectra for the pressure (sea level) and currents at this station. The semidiurnal tidal peaks dominate the variance of both sea level and current velocity. Although the tides are the largest energy signal seen in the Massachusetts Bays elevation and currents, they are a periodic signal, moving the water back and forth. There is no net transport associated with the tides except as non-linear tidal rectification. However, in helping suspend particulate matter, tides, internal tides, and internal waves can be important.

There are basically three tidal analysis techniques used to look at the Massachusetts Bays records.

1. The classic method of harmonic analysis was devised by Lord Kelvin in 1867, expanded by the work of Sir George Darwin, A. Doodson and others and adopted by the US Coast and Geodetic Survey (Schureman, 1941). Dennis and Long (1971) produced a computer program using this method which has been further revised to the program used here (Irish and Brown, 1986).
2. The response method was devised by Munk and Cartwright (1966) to separate the astronomical gravitational forcing function from the ocean's response. It's methodology allows other inputs such as radiational tides (wind induced sea level changes) and runoff to be formally analyzed.
3. The Least Squares method implemented by Foreman (1977) is based on the methods suggested by Godin (1972), and has the advantage of handling records with data gaps.

Each method has advantages and all were used on the pressure and current records from Stellwagen Bank for comparison.

The Stellwagen Bank bottom pressure record was selected because it was not in a bay or harbor, such as Boston sea level recorder, or Gloucester or Provincetown Coast Guard pressure records, so might better represent the force driving the tides in the Massachusetts Bays system. Table T1 shows the comparison of the results from the three methods for the ten largest amplitude diurnal, semidiurnal and higher harmonic frequencies. The pressures have been divided by the average sea water density and gravitational acceleration to convert the pressure to an equivalent sea water elevation in cm. This factor is 99.55 cm/dbar at this site (taking an averaged density of 1025 kg per cubic meter and a gravitational acceleration of 9.80 meters per second squared), so the amplitudes are tabulated in cm elevation. The phase is reported relative to the Greenwich meridian and called the Greenwich epoch. The amplitude and phases are reported at the tidal constituent frequencies, and allows a prediction of the tides to be made for any future or past time.

The results from the different techniques are in good agreement except at the S2 frequency. The response analysis also considered a semidiurnal radiational component and so gets a different S2 amplitude and phase which was selected to produce a smoother admittance to gravitational forcing. (See table T2) The rest of the coherent energy at the S2 frequency was the put into the radiational tidal component. This radiational component is listed in parentheses after the gravitational component in the response column of table T1. Neither of the other two analysis techniques separate out the radiational component, which has proved to be considerable, and often confuses tidal analysis in coastal regions.

The admittance function from the response analysis (table T2), relative to the gravitational tidal potential is plotted in figure T3. The response function can only be estimated at the tidal frequencies where we know the forcing function. These discrete points are connected as with solid line in the diurnal and semidiurnal bands. Outside of these bands we have no information on the ocean's response function. The diurnal admittance is relatively flat with modest phase shift. The semidiurnal frequency amplitude gain changes by a factor of 3 with large accompanying phase shift. Again this emphasizes the resonance which makes the M2 the largest signal present.

It is also obvious from figure T2 and table T1 that most of the energy in the pressure (sea level) fluctuations on Stellwagen Bank is in the principal lunar constituent, M2. An analysis of the variance in the record (out to the Nyquist frequency of 0.5 cph) shows that the total variance (energy) in the diurnal tidal band is only 2.0% of the total record variance. However, the tidal analysis by the harmonic method predicts 99.6% of the energy in diurnal band. The prediction is good, but the diurnal tides are small compared with the semidiurnal tides, as was seen in figure T2. After a full tidal analysis, the residual variance, which contains the low-frequency weather induced background sea level fluctuations, accounts for only 2.0% of the total observed energy, i.e., the tides are 98% of the total energy.

The energy in the semidiurnal tidal band on Stellwagen Bank accounts for 95.3% of the total observed variance in pressure record (the sea level). Again, the harmonic analysis predicts 99.6% of the energy in the semidiurnal tidal band. The principal Lunar constituent, M2, represents 96.3% of the variance in the semidiurnal band, or 92.1% of the total record variance. Therefore, because of the response of

North Atlantic and the resonance of the Gulf of Maine system, the semidiurnal tides are amplified and dominate. The M2 is amplified more than the S2 which enables one to represent the surface elevation as a single sine wave with the amplitude and phase of the M2 constituent and explain more than 92% of the observed pressure (sea level) energy.

Using Defant's (1961) characterization of tidal type, the ratio of diurnal (K1 + O1) to semidiurnal (M2 + S2) amplitudes is 0.17 which is less than 0.25, so the tides are classified as semidiurnal. Using this criteria along the northern east coast of the United States, the tides are classified as semidiurnal or mixed with the ratio varying from 0.17 to 0.28 depending on the location. The diurnal tides are not important relative to the semidiurnal and can probably be ignored to the first order in Massachusetts Bay.

Figure T2 also shows that there are significant higher harmonics of the tides present. These higher harmonics (Terdiurnal, Quarterdiurnal, and Hexdiurnal frequencies) are called overtides (analogous to overtones) or compound tides and are an interesting study in themselves. Although these frequencies are present in the gravitational driving force, they do not predict compound tides as large as seen in coastal regions. These tides are most often associated with non-linear interactions of the principal tidal lines which are attributed to shallow water effects. In large rivers this appears as a steepening of the flood over the ebb tidal elevation which increases as one goes upstream, e.g. the Delaware River and Bay (Parker, 1991). Since the tides are a sum of sine waves at specific frequencies, non-linear effects cause the transfer of energy into sine waves at the sum and difference frequencies. A study of the compound tides in the Massachusetts Bay and the Gulf of Maine system might help with a better understanding of the tides of the region and the response of the Gulf of Maine system. This may be important if Canadian tidal power plants do change the resonance frequency of the Gulf of Maine. By lowering the resonant frequency, the height of the tide in the Bay of Fundy and Massachusetts Bay may be increased. However, since the energy associated with these higher harmonics, is, again, quite small compared with the semidiurnal energy, further discussion is not warranted here. It is interesting to note that in the current records these higher harmonics are of the same amplitude as the diurnal currents (figure T2).

A harmonic analysis was done on all the observed pressures and elevation data for Massachusetts Bay. Pressures were analyzed as pressure records, and the results converted to elevation by multiplying by 99.55 cm/dbar. These results are tabulated for the 5 main diurnal and semidiurnal constituents in Table T3. Where there are several separate deployments with gaps of less than one month which make up an observation at one location, the individual sections were analyzed, then the records were joined together using a tidal prediction from the longest adjacent section to fill the gap to create one long record. The results from this analysis is also shown, and when the length exceeds one year, the first and last 365 days are analyzed and both results shown. Also, for comparison with tides in the region Table T3 lists a few other selected stations from Moody et al., (1984), and Irish (1990). This source also lists results for tidal analyses for stations located along the coast and shelf from the Mid-Atlantic Bight up into the Canadian Maritime Providences.

These results are summarized on a cotidal chart (figure T4) which shows spatial variation in the amplitude and phase of the M2 constituent. Cotidal charts for the O1, K1, N2 and S2 constituents show a similar picture so are not shown. In Massachusetts Bay, the water level appears to rise and fall with nearly the same amplitude at nearly the same phase. There is a slight amplification and phase lag in Boston harbor and a small amplification in Provincetown, probably associated with the location of the pressure gauge behind the tip of Cape Cod at the Coast Guard station. To within 15 minutes in phase and a few percent in amplitude, the surface elevation in Massachusetts Bay can be considered to rise and fall the same amplitude at constant phase for all the tidal constituents. However, simple and uncomplicated the surface elevation looks, it is not reflected in the currents which are subject to the effects of the bathymetry and presence of strong internal waves.

Tidal Currents

The pressure gradient due to the rising and falling sea surface forces tidal currents which move at the same frequency, but whose behavior is also modified by the bathymetry, e.g., shallower water causing faster currents, or flow being directed along depth contours. Thinking of this another way, the water has to flow into Massachusetts Bay to cause the nearly simultaneous rise in sea level observed. The total volume of the flow is well behaved, but the actual path of the currents and their velocity is controlled by the bathymetry.

In addition, the analysis of the currents for their tidal content, is confused by the presence of internal waves. These waves are generated by the tidal currents flowing over topography, but propagate as internal waves with characteristics controlled by the density structure of the water column. They are generated with a fixed phase relationship to the surface tide at the generation site, and therefore are hard to separate from the currents directly associated with the gravitational tides. To the first order they do not show up in the pressure or sea surface records, since there is little surface elevation, the maximum elevation occurring somewhere in mid-water column, depending on the density stratification. However, internal waves to have a strong current component, especially at the surface and bottom, which makes tidal analysis more difficult.

That part of the tidal currents that is directly attributed to the barotropic or surface tide can be predicted by standard tidal theory once a "proper" analysis is completed. But tidal theory does not allow prediction of the amplitude and phase of the internal tide, and our normal tidal analysis techniques do a poor job of separating the barotropic part of the currents from the baroclinic or internal wave part. The amplitude and phase of the internal tide changes with season as the water stratification changes, since it is the vertical density gradient which controls the speed and propagation of the internal tides. Because of this, there may be some chance of separating the two components by using long records and looking at the part of the signal that has a single amplitude and phase relationship over the entire record length with changing season. This technique may work because the longer record gives a better frequency resolution and the internal tides are "broad-banded" by the changing density field, so they can be separated out by an analysis for line frequencies. Therefore, the discussion of the currents in this section must consider the internal wave energy which is examined again in more detail the next section. Another method is to analyze the tides during the winter when the water column in Massachusetts Bay is well mixed, since internal waves can only exist when there is a density stratification. A tidal analysis done during the winter months when the water column is well mixed should represent the surface or barotropic tidal component in the velocity observations. However, even though there is no temperature gradient during the winter, there is a small salinity gradient which would allow some internal oscillation to be present, although small. Therefore, the winter period (from November into March) is nearly without internal waves.

The spectra of the bottom velocity at 27 meters depth over Stellwagen Bank (figure T2), shows that the semidiurnal tidal currents dominate. The diurnal tidal currents are barely above background level, and about as strong as the higher harmonic or compound tides. The inertial currents (0.056 cph) can be seen in the spectrum, but are barely significant. Since this spectrum extends over nearly a year, it contains data when the internal tides is large and boosts the amplitude of the semidiurnal and higher frequency tides over the diurnal because a free internal waves can not propagate frequencies below the inertial. Therefore, the results can again concentrate on the M2 tidal currents as representative of the majority of the energy.

The 300 day long current record from 27 meters depth on Stellwagen Bank was analyzed in detail to examine the sensitivity of the analysis techniques for contamination by the internal tide. Stellwagen Bank is a unique location as it is in the region of internal tidal generation, so may be the hardest record to separate the barotropic and baroclinic tides. The analysis of the single, long record was done by the three methods, as well as the winter time by the Least Squares technique, to see if the modulation of the internal tide would separate the barotropic and baroclinic portions. The results are of this comparison are listed in Table T5. Generally the three methods give similar results, but definitely do not agree as well as they did for surface tidal elevations (see table T1).

From the harmonic analysis, the residual variance (that part not predicted by the tidal analysis) is 77.4% of the observed variance. The semidiurnal band has 75.4% of the observed variance, but analysis only predicts 21.9% of the variance in the semidiurnal band. Again the M2 constituent is 94.6% of the predicted tide in the semidiurnal band, but only 20.7% of the total variance. Currents are more difficult to analyze than pressure or tidal elevation because they are contaminated with a higher background or non-tidal internal wave signal. In the deep ocean a tidal analysis can typically predict 2/3 of the variance. Here, in the coastal ocean, tidal analysis predicts only 1/4 of the variance as barotropic tide, or that portion of the signal consistent with tidal theory. The majority of the signal in the semidiurnal tidal band is due to internal tides, which, during the stratified seasons, can dominate the velocity observation.

Since internal waves can only exist in the presence of a density stratification, an analysis of the records during the winter time, i.e. November 1990 through March 1991, when the water column in Stellwagen Basin was observed to be nearly homogeneous, should be least contaminated with internal tide energy. The "Winter Only" Least Squares analysis on the right hand side of table T5 uses just the winter section (1 November 1990 to 1 March 1991) for the analysis and, if anything, predicts more of the variance than the three methods for the entire record with "neutral" patches for the missing data. However, the Least Squares technique is mechanically much easier to apply to the winter part of the record because of the complications caused by the gap in the data due to mooring servicing and repair. The analysis of the 300 day record relied on filling the gap with a neutral patch, which can be a significant portion of the winter record. Therefore, the Least Squares technique was applied to the winter period to analyze for the tides, and represent the currents with least internal tide effects. The results for the M2 constituent are given in table T6, and summarized as current ellipses for the 5 to 8 meter velocity records in figure T5.

The tidal analysis programs analyze the East and North velocity components separately, and then convert the results to an elliptical representation of the currents. Thus the two amplitude and phases are represented as the amplitude of the maximum axis and the amplitude of the minimum axis. The sign of the minor axis indicates the direction of the current vector rotation. A positive minor axis implies counter-clockwise rotation, and a negative minor axis implies clockwise rotation. The phases become the tilt of the major axis from North, with positive angle being clockwise rotation. The Greenwich phase remains a Greenwich phase, but is now the phase of the maximum velocity of the major axis in the upper sector (tilts between -90 and +90 degrees) following the convention of Butman (1975) and Moody et al., (1984).

The mooring in Stellwagen Basin (figure T1) had a 150 kHz solar-powered downward-looking Doppler acoustic profiler beneath the surface buoy. The profiler recorded 4.3 meter vertical averages of currents at 17 vertical depths from 8.3 meters through 77.8 meters below the surface. These records were analyzed for their tidal content for the winter and the spring records and the results listed in table T7. The top two sections of the table give the results for the two parts of the winter record. The second part is 42 days long (the first part was 32 days long) and was selected as representative of the barotropic tidal currents. The results are similar to the first part, so no patching was attempted, but would probably give more stable, but not very different results. These results are plotted in figure T6 which shows the amplitude and phase of the two velocity components versus depth at the bottom, and a summary plot of all nine tidal ellipses at the top. The currents become more elliptical (less circular) and increase slightly in amplitude with depth. The orientation of the major axis remains nearly constant as does the Greenwich Phase. These results are as expected for the currents without internal waves. The currents under a long wave such as the tides should have a single orientation or tilt and have a constant Greenwich phase. The amplitudes of the two components will change slowly with depth as influenced by topography, but generally show no significant effects except for the bottom boundary layer. No turning is seen, and the velocity of the deepest depth is only showing a small effect of the bottom boundary layer reducing the amplitude. The results is a current which is nearly the save from the top to the bottom of the water column.

The tidal analysis of the winter data from table T6 and table T7 is summarized in figure T5 for the surface currents at 4 to 8 meters depth. The depth dependence is illustrated in the more complicated figure T7. The tidal ellipses from the various depths at a station are stacked one above the other with the shallowest on top. The whole stack is located roughly where the mooring is located, except for the Stellwagen Basin mooring whose profile is shown on the left with an arrow locating where is should be positioned. To the first order there is little change in the currents with depth, and the currents are nearly back and forth motion in a very elliptical manner. Therefore, we believe that it is a good representation of the barotropic or component of the tide that can be predicted for other times using harmonic tidal theory and has minimum contamination with the internal tide. However, there is still a major amount of energy remaining in the tidal frequency band which is related to the internal tide, and discussed below. Also, additional tidal analyses for other constituents and time periods are included in the internal tide section because they are contaminated with the internal tidal effects.

The strongest tidal currents are seen in the South Channel between Race Point and Stellwagen Bank. M2 tidal currents exceed 40 cm/sec at all depths (except the tripod data in the boundary layer very near the bottom). This added velocity is required to move the volume water into Cape Cod Bay which is required to rise the sea level evenly. The currents in the North Channel are typically 12 cm/sec, and less than 1/3 those in the South Channel. There is less volume of water required to fill the tidal prism in the Northern part of Massachusetts Bay, so the velocities are smaller. Over Stellwagen Bank the velocities are a bit larger, due to the shoaling over the bank, but not like in the South Channel. The Tidal ellipses are plotted in figures T5 and T7 so that the tidal excursion (the actual path taken by a parcel of water moving through the tidal eclipse as measured at the mooring) is 5 times larger than reality. The currents off Manomet Point and in Cape Cod Bay are South and North as required to move water into Cape Cod Bay, but smaller in amplitude since there is a wider cross section through which to move the water. At the Boston Buoy the currents are in and out of Boston Harbor, still with remarkably elliptical flow. The currents in Broad Sound show the most circular ellipses, and are aligned more with the Bathymetry. The typical tidal current in Massachusetts Bay (away from the mouth and channels) is about 10 cm/sec from top to bottom. The strong structure seen in the currents during other seasons (typified by the third section in table T7) is due to the internal tides as discussed below.

Internal Tides

In regions where there are topographic barriers such as Stellwagen Bank between the Gulf of Maine and Massachusetts Bay, the tide is forced up and over the bank and down into Stellwagen Basin. This creates strong, periodic currents which distort the density structure of the water column in the region of the bank, and generate internal tides (Rattray et al., 1969; Baines, 1973; Halpern, 1971; Haury et al., 1979; and Chereskin, 1983). These internal waves at tidal frequency exist on the stratification in the water column, and disappear during well mixed times in the winter. In the spring, summer and fall they can become quite large, and have the potential to break and cause mixing in the water column. The generation of internal tides extracts energy from the surface tides to create the internal waves. These waves can then propagate into coastal regions and to the bottom of the deep bays to increase the current velocity which in turn may resuspend sediments.

The data collected in Massachusetts Bay clearly show a barotropic tide and currents with a strong internal tidal component superimposed during the portion of the year when the water column is stratified. Vertical excursions are often greater than 10 meters in water as shallow as 40 meters in Cape Cod Bay, and as great as 20 meters in the deeper Stellwagen Basin. Figure T8 shows a depth recorder record taken near the UNH mooring in Cape Cod Bay. The top and bottom (40 meters) are clearly constant, while the strong density gradient regions which are marked by high acoustic scattering are observed to move up and down. The ship was nearly stationary by the buoy and the internal wave was observed to propagate past the ship. During the July servicing when the water was calm, bands of internal wave slicks were observed on the radar where convergence zones had fewer ripples, and scattered the radar signal less, as was also seen by Trask and Briscoe (1983). They also showed synthetic aperature radar images from SEASAT showing the spatial distribution of the surface effects of the internal waves in Massachusetts Bay which clearly indicate that the waves are radiating shoreward from Stellwagen Bank.

The winter tidal velocities are typically less than 20 cm per second (reaching a maximum of nearly 1 knot in the channel North of Race Point) and aligned as one would expect for moving the water in and out of Massachusetts Bay to produce the observed tidal elevation change. Figure T9 shows the tide elevation and current on Stellwagen Bank from mid-November through mid-December. The current is very regular with an equal inflow and outflow. The strongest tidal currents were seen over Stellwagen Bank during the summer when the twice a day velocities (in the generation region of the internal tides) regularly exceed 1 knot (see figure T10). The tidal elevation is still the same, and the flow out of Massachusetts Bay is about the same, but the flow in to the Bay is now over twice as large. This additional energy is due to the internal tides. Tidal velocities during the winter (from November into March) are typically only half those seen the rest of the year due to the absence of internal tides when the Bays are well mixed. In Stellwagen Basin, there is a small intensification of tidal velocities with depth. During calm weather, these internal waves cause bands of surface slicks which can be seen with the eye and on radar. By distorting the density field, the internal tides make it difficult to interpret the Bays wide hydrographic surveys, and mask the lower frequency wind and density driven circulation signals in moored observations. Internal waves exist everywhere and must be considered as a significant source of energy along with the waves, wind and density driven currents when considering the resuspension and transport of sediments in the Mass Bays system.

The current record from the bottom on Stellwagen Bank from summer through winter (figure T11) shows a marked change in amplitude of the velocity near 1 November 1990. This is the time when the temperature and salinity in Stellwagen Basin became well mixed vertically (figure 2.2-7) and could no longer support internal oscillations. The amplitude of the velocity is clearly less than one half during the winter. This is again seen in the Stellwagen Basin Doppler profiler record which were analyzed by the harmonic method for the spring 1991 period (table T7 and figure T12). There velocity record now obviously depth dependent at M2 frequency. The current ellipses are now observed to turn clockwise with depth, and the ellipticity and magnitude show greater change. The amplitude and phases (bottom of figure T12) also show this baroclinic behavior in the flow.

To try and separate the internal wave component from that part of the current due to the surface elevation, the winter tidal prediction was used to predict the tidal velocities for the spring period, and to subtract the predicted barotropic tide from the observed to leave the baroclinic tide and background velocity fluctuations. This baroclinic and background current record was then again analyzed for the M2 component of the tide, to separate out the background signal. The results are listed at the bottom of table T7 plotted in figure T13. The amplitudes (lower panel) show a maximum at the surface and bottom, and a minimum at about 40 meters, just below the pycnocline. The phases show a 180 degree phase reversal at this depth. The ellipses (top of figure T13) now are nearly circular, and are largest at the surface and bottom with a minimum amplitude at mid-depth. This is clearly a first mode internal oscillation with the surface and bottom currents 180 degrees out of phase, and the maximum horizontal velocities occurring at the top and bottom and the greatest vertical amplitudes seen at mid-depth!

The internal tidal analysis at the bottom of table T7 is only at the M2 frequency, while the semi-diurnal internal tide band is wider. The analyzed amplitude is about half that of the barotropic currents, but from the time series and spectra, it is obvious that the semi-diurnal internal tide is the same size as the barotropic currents.

With this caution of the potential contamination of a tidal analysis due to internal tidal effects, the tides from all four seasons were analyzed by the Least Squares technique and the results given in table T8 for the O1 constituent, table T9 for the K1 constituent, table T10 for the N2 constituent, table T11 for the M2 constituent, table T12 for the S2 constituent, table T13 for the M4 compound tidal constituent and table T14 for the M6 compound constituent. The seasons were (1) winter from 1 November to 1 March, (2) spring from 1 March to 1 June, (3) summer from 1 June to 1 September, and Fall from 1 September to 1 November. The divisions were roughly based on partitioning the year into four pieces during which similar processes and statistics were occurring.

TABLE T1 - Stellwagen Bank Bottom Pressure Tidal Analysis
Comparison for the three tidal analysis methods.

Tide Line	Harmonic	Response	Least Squares
Darwin Symbol Freq. (cpd)	H (cm) G (degrees)	H (cm) G (degrees)	H (cm) G (degrees)
Q1 0.893244	2.10 359.8	2.07 171.2	2.0 164.0
O1 0.929536	10.82 186.7	10.71 185.3	10.9 186.0
P1 0.997262	4.57 175.2	4.62 203.3	4.2 201.7
K1 1.002738	13.80 203.5	13.73 204.0	13.5 204.4
N2 1.895982	27.15 72.5	26.80 77.0	28.0 74.1
M2 1.932274	122.75 108.3	122.70 108.2	122.8 108.4
S2 2.000000	18.94 141.9	30.50 (8.90) 145.6 (335.2)	18.9 142.3
K2 2.000000	5.15 144.7	6.40 148.9	5.2 142.0
M4 3.864547	1.26 341.0	- -	1.2 343.4
M6 5.864547	1.04 287.3	- -	1.2 283.1

Note: (1) decibars were converted to cm by multiplying by 99.55
(2) the semidiurnal radiational tide from the response analysis is listed in parentheses and is added to the gravitational tide to get the observed tide.

Table T2 - Stellwagen Bank Bottom Pressure Response Analysis

Reference is Tidal Potential G21, G22, R22 (Cartwright et al., 1969)

***** DIURNAL TIDES *****

FREQUENCY CPD	ADMITTANCE OBS LEADS REF BY PHASE AMP	PHASE	TIDAL LINES MOST SIGNIF	CPD	MOST CENTRAL	CPD	RESULTING CONSTITUENTS H	G
0.892935	0.004256	8.817	Q1	0.893244	Q1	0.893244		
0.929536	0.004145	-5.234	01	0.929536	01	0.929536	10.71	185.3
0.966137	0.004016	-16.746	M1	0.966446	M1	0.966446		
1.002738	0.003742	-24.015	K1	1.002738	K1	1.002738	13.73	204.0
1.039339	0.003250	-25.500	J1	1.039030	J1	1.039030		
0.893244	0.004255	8.695	01	0.929536	Q1	0.893244	2.07	171.2
0.997262	0.003796	-23.250	K1	1.002738	P1	0.997262	4.62	203.3

***** SEMIDIURNAL TIDES *****

FREQUENCY CPD	ADMITTANCE OBS LEADS REF BY PHASE AMP	PHASE	TIDAL LINES MOST SIGNIF	CPD	MOST CENTRAL	CPD	RESULTING CONSTITUENTS H	G
1.859071	0.030598	-42.526	MU2	1.864547	2N2	1.859690		
1.895672	0.022328	-75.087	N2	1.895982	N2	1.895982		
1.932274	0.019538	-108.232	M2	1.932274	M2	1.932274	122.70	108.2
1.968875	0.016177	-130.759	L2	1.968565	L2	1.968565		
2.005476	0.007769	-149.227	S2	2.000000	K2	2.005476	6.40	148.9
1.895982	0.022287	-75.392	M2	1.932274	N2	1.895982	26.80	77.0
2.000000	0.009394	-145.848	S2	2.000000	S2	2.000000	30.50	145.6

***** RADIATIONAL TIDES *****

FREQUENCY CPD	ADMITTANCE OBS LEADS REF BY PHASE AMP	PHASE	TIDAL LINES MOST SIGNIF	CPD	MOST CENTRAL	CPD	RESULTING CONSTITUENTS H	G
2.000000	0.160137	24.903	S2	2.000000	S2	2.000000	8.90	335.2

RECORDED VARIANCE = 0.825100E+00 (in dbars)
PREDICTED VARIANCE = 0.810263E+00 = 98.2% of recorded variance
RESIDUAL VARIANCE = 0.148365E-01 = 1.8% of recorded variance

TABLE T3 - Historic Harmonic Tidal Constants for the Gulf of Maine and Massachusetts Bay in order of decreasing importance.

From Moody et. al. (1984): (Amplitudes reported in cm)

Station	Latitude Longitude	Record days	M2 H(cm) G(deg)	N2 H(cm) G(deg)	S2 H(cm) G(deg)	K1 H(cm) G(deg)	O1 H(cm) G(deg)
Nauset	41.82 69.93	58	103.2 102.	22.2 70.	14.4 133.	13.1 201.	11.5 182.
Cape Cod Light	42.05 70.08	29	116. 113.				
Cape Cod Canal	41.77 70.50	369	124.4 109.	28.9 74.	19.9 144.	13.1 206.	10.8 187.
Portsmouth N.H.	43.08 70.73	365	130.3 107.	27.8 76.	20.3 143.	14.1 204.	11.2 185.
Portland Maine	43.65 70.25	1845	133.0 103.	29.6 73.	21.7 138.	13.9 202.	11.1 183.
Cashes Ledge	43.18 69.08	57	120.0 98.	28.2 66.	19.5 126.	12.5 198.	10.1 186.

From Irish (1990): (Amplitudes reported in decibars and were multiplied by 99.55 to get cm)

Station	Latitude Longitude	Record days	M2 H(cm) G(deg)	N2 H(cm) G(deg)	S2 H(cm) G(deg)	K1 H(cm) G(deg)	O1 H(cm) G(deg)
Wilkinson Basin	42.515 69.483	80	111.0 94.0	25.3 63.4	24.1 140.5	12.4 200.2	10.0 182.5
Georges Basin	42.523 67.215	391	81.1 77.7	18.1 50.5	16.6 113.1	10.8 191.5	8.6 179.0

TABLE T4 - Harmonic Tidal Constants for Massachusetts Bays

Harmonic Analysis of Mass Bays Program Pressure Observations
(Amplitudes were multiplied by 99.55 to get cm)

Station		Latitude Longitude	Record days	H(cm) G(deg)	M2 H(cm) G(deg)	N2 H(cm) G(deg)	S2 H(cm) G(deg)	K1 H(cm) G(deg)	O1
Provin-	1	41.9667	60	134.1	27.5	21.9	13.0	11.9	
cetown		70.6633		112.2	75.4	146.3	201.7	192.7	
Coast									
Guard	2		243	133.5	30.0	20.3	13.8	11.4	
				106.6	72.3	141.9	204.8	185.6	
	3		186	132.4	30.5	21.4	14.5	11.4	
				111.9	75.9	146.7	208.6	189.7	
	YR1		365	133.3	29.9	21.0	13.8	11.4	
				106.5	72.3	142.6	204.6	185.6	
	YR2		365	131.9	30.4	20.3	13.6	11.1	
				109.0	75.8	144.6	205.9	186.0	
Stell-	1	42.3718	10	131.6	23.0	13.7	12.0	10.7	
wagen		70.3483		108.1	81.9	148.3	217.0	163.1	
Bank									
Bottom	2		171	122.4	27.9	17.0	13.8	10.8	
Pressure				108.5	76.0	138.4	203.6	185.1	
	3		102	122.8	27.4	19.4	14.7	10.9	
				107.6	71.3	141.9	204.1	190.9	
	Sum		300	122.8	27.2	18.9	13.8	10.8	
				108.3	72.5	141.9	203.5	186.7	
Stell-	1	42.3552	123	122.1	27.9	19.8	13.3	10.4	
wagen		70.4002		105.8	72.9	137.2	202.0	183.1	
Basin									
	2		67	123.1	27.2	19.7	14.9	11.6	
				106.6	70.3	141.0	202.3	188.2	
	Sum		207	122.2	27.9	21.9	13.4	10.7	
				104.4	71.7	156.3	202.7	182.4	
North		42.5223	138	122.8	28.6	18.6	13.2	11.3	
Channel		70.4877		113.0	71.2	148.4	206.7	191.2	

TABLE T4 - Harmonic Tidal Constants for Massachusetts Bays Cont.

Station		Latitude Longitude	Record days	M2 H(cm) G(deg)	N2 H(cm) G(deg)	S2 H(cm) G(deg)	K1 H(cm) G(deg)	O1 H(cm) G(deg)
Glouc-ester	1	42.0617 70.2433	47	129.0 107.0	27.6 66.8	21.6 139.5	13.5 200.9	12.0 191.8
Coast Guard Station	2		83	126.9 108.2	27.7 74.2	17.4 150.4	14.6 210.0	10.9 183.5
	3		204	126.1 106.4	28.3 72.0	18.1 147.4	13.9 205.6	11.1 185.1
	2&3		288	126.5 106.8	28.6 72.8	19.7 142.6	13.5 204.8	10.9 183.7
Boston Light Buoy	1	42.3767 70.7817	50	129.6 108.4	28.6 85.5	18.9 144.6	13.8 207.1	11.5 188.2
Bottom Pressure	2		109	127.0 105.6	28.5 72.1	20.0 140.1	14.1 207.8	11.2 184.1
Boston Sea Level		42.35 70.05	365	135.4 109.8	30.3 76.6	20.8 147.8	14.0 206.8	11.1 184.9

TABLE T5 - Stellwagen Bank Bottom Currents at 27 meters depth (2 m above the bottom). Tidal Analysis Comparison from 300 day record for the 5 main tidal constituents. Gaps in the observed record were filled by a tidal predictid from a neighboring section as a "neutral" filler.

Tide Line	Harmonic		Response		Least Squares		Least Squares (Winter Only)	
Darwin Symbol Freq.(cpd)	Major Minor	Phase Tilt	Major Minor	Phase Tilt	Major Minor	Phase Tilt	Major Minor	Phase Tilt
O1	0.52	79.2	0.49	75.1	0.49	78.0	0.55	139.5
0.929536	0.08	27.3	0.08	29.1	0.09	27.8	0.04	27.3
K1	1.03	110.1	0.99	104.3	0.90	114.3	0.81	133.3
1.002738	-0.08	31.5	-0.13	26.0	-0.13	33.3	-0.05	72.7
N2	2.32	227.5	2.48	199.1	2.33	235.7	3.40	10.8
1.895982	-0.21	63.4	-0.55	63.1	-0.25	65.6	-0.26	60.4
M2	9.01	293.0	8.90	293.0	9.89	296.2	13.92	42.7
1.932274	-0.90	55.5	-0.90	55.6	-0.59	56.7	-0.16	61.3
S2	1.42	318.1	2.10	275.3	1.69	330.7	2.86	50.7
2.000000	-0.11	53.4	-0.10	76.7	-0.19	57.0	-0.22	31.8
M4	0.45	43.6	-	-	0.47	40.9	0.76	345.4
3.864547	0.15	11.1	-	-	0.17	11.4	0.27	28.9
M6	0.94	187.6	-	-	1.12	186.4	1.31	251.4
5.864547	-0.06	39.6	-	-	-0.07	39.6	-0.12	34.5

Major and Minor are amplitudes of the tidal ellipse in cm/sec.
If the minor axis is negative, then the current rotation is clockwise.
Phase is relative to Greenwich of the Maximum axis in the upper sector.
Tilt is the orientation of the maximum velocity axis clockwise from the north or vertical.
Winter Only is a Least Squares analysis for 1 November 1990 through 1 March 1991.

TABLE T6 - Massachusetts Bay Currents Tidal Analysis of M2 Constituent for period from 1 November 1990 to 1 March 1991 by the Least Squares Method. Results marked 1989 are from the same period in the previous year.

Station and Depth	Major cm/sec	Minor cm/sec	Tilt rel N	Phase in G	
Broad Sound @ 5 m	16.11	1.41	49.7	219.8	
Broad Sound @ 18 m	9.96	1.26	65.9	188.6	
Boston Buoy @ 5 m (1989)	9.43	-0.66	77.1	204.0	
Boston Buoy @ 5 m (1990)	9.85	-0.98	76.9	203.9	
Boston Buoy @ 23 m (1989)	9.10	-0.30	87.1	196.6	
Boston Buoy @ 23 m (1990)	7.71	0.55	-82.0	6.7	(Short)
Boston Buoy @ 33 m	6.69	0.59	77.0	185.1	
Manomet Point @ 5 m	11.26	0.03	-4.9	211.1	
Manomet Point @ 29 m	10.61	0.64	-1.3	207.3	
Race Point @ 05 m	40.81	3.28	54.3	200.2	
Race Point @ 23 m	43.47	-1.07	53.1	201.4	
Race Point @ 55 m	42.64	0.37	62.0	189.1	
Race Point @ 60 m	30.11	0.46	67.9	184.0	
Scituate @ 5 m	7.80	1.21	45.6	202.9	
Stellwagen Basin @ 75	13.49	0.88	-88.3	8.6	(Short)
Stellwagen Basin @ 84	7.94	1.64	-84.6	356.9	
North Channel @ 4 m	8.28	1.46	78.6	232.5	
North Channel @ 25 m	13.90	2.08	-89.5	50.1	
North Channel @ 60 m	11.21	2.86	84.3	237.4	
Stellwagen Bank @ 04 m	15.36	-1.27	68.6	231.7	
Stellwagen Bank @ 25	13.92	-0.16	61.3	42.7	
Cape Cod Bay @ 4 m	13.45	-0.24	-4.3	222.6	

If the minor axis is negative the current rotation is clockwise.
Tilt is the orientation of the maximum velocity axis clockwise from North.
Records labeled "short" are less than one month long

Table T7. Harmonic Analysis of the Stellwagen Basin Doppler Profiler Record for Tides and Internal Tides at the M2 Frequency

Winter Velocities, Part One - 8 November 1990 to 10 December 1990.

	Eastgoing		Northgoing		Ellipse			
DEPTH	H	G	H	G	Major	Minor	Phase	Tilt
meter	cm/sec	degree	cm/sec	degree	cm/sec	cm/sec	degree	degree
8.3	8.152	189.73	3.363	236.11	8.505	2.334	14.6	72.8
17.0	10.234	189.89	3.938	237.59	10.598	2.813	14.1	74.4
25.7	10.844	188.69	4.029	239.23	11.167	3.021	12.7	75.6
34.4	11.006	189.03	4.107	237.84	11.359	2.995	13.0	75.1
43.1	11.091	189.02	4.033	236.19	11.448	2.865	12.8	75.2
51.7	11.697	188.59	3.885	228.48	12.087	2.411	11.6	75.1
60.4	12.635	188.55	3.786	224.42	13.013	2.154	10.9	76.0
69.1	13.652	187.70	3.255	213.62	13.965	1.391	8.9	77.8
77.8	12.785	184.18	3.114	209.97	13.092	1.323	5.5	77.5

Winter Velocities, Part Two - 1 February 1991 to 15 March 1991.

DEPTH	H	G	H	G	Major	Minor	Phase	Tilt
meter	cm/sec	degree	cm/sec	degree	cm/sec	cm/sec	degree	degree
8.3	10.535	188.74	4.151	246.18	10.797	3.414	13.0	76.7
17.0	10.873	188.61	4.380	246.44	11.150	3.615	13.1	76.4
25.7	11.187	189.59	4.391	243.90	11.507	3.467	14.0	75.8
34.4	11.702	189.93	4.273	237.89	12.072	3.077	13.8	75.3
43.1	12.149	190.83	4.209	230.48	12.593	2.591	14.1	74.4
51.7	12.605	192.39	4.390	224.38	13.161	2.227	15.3	73.0
60.4	13.305	193.86	4.610	216.54	13.979	1.692	16.1	72.0
69.1	13.967	193.85	4.649	211.07	14.662	1.312	15.5	72.2
77.8	13.627	189.81	4.310	210.30	14.220	1.446	11.6	73.3

Spring Velocities - 15 March 1991 to 18 June 1991.

DEPTH	H	G	H	G	Major	Minor	Phase	Tilt
meter	cm/sec	degree	cm/sec	degree	cm/sec	cm/sec	degree	degree
8.3	9.492	217.73	9.567	231.19	13.384	1.579	44.5	44.8
17.0	8.302	214.57	10.386	237.21	13.051	2.543	48.5	38.1
25.7	8.038	200.35	8.429	247.71	10.669	4.671	45.5	43.0
34.4	9.340	191.74	6.436	252.89	10.065	5.231	25.9	64.2
43.1	11.441	188.62	4.590	254.92	11.611	4.142	12.4	79.5
51.7	13.878	186.10	2.651	247.35	13.938	2.314	7.0	84.6
60.4	15.894	183.63	1.028	204.08	15.923	0.358	3.7	86.5
69.1	16.825	178.77	1.229	85.43	16.825	-1.227	178.8	-89.8
77.8	16.269	171.46	1.840	35.39	16.323	-1.272	171.8	-85.3

Table T7. Harmonic Analysis of the Stellwagen Basin Doppler Profiler Record for Tides and Internal Tides at the M2 Frequency Cont.

Spring Internal Tides - 15 Mar - 18 June 1991.

DEPTH meter	H cm/sec	G degree	H cm/sec	G degree	Major cm/sec	Minor cm/sec	Phase degree	Tilt degree
8.3	5.091	304.01	5.682	220.09	5.790	-4.968	59.1	21.9
17.0	4.963	321.42	6.125	230.45	6.126	-4.961	48.6	-2.3
25.7	3.589	344.75	4.063	251.80	4.081	-3.568	61.9	-11.2
34.4	2.336	3.03	2.557	278.69	2.607	-2.280	119.7	23.7
43.1	0.787	46.99	1.886	321.50	1.887	-0.784	142.4	2.3
51.7	1.955	141.61	2.176	16.28	2.604	-1.333	173.2	-39.7
60.4	3.688	143.96	3.590	40.13	4.054	-3.172	178.9	-48.2
69.1	4.976	131.85	5.428	41.79	5.428	-4.976	41.5	-0.3
77.8	5.467	119.88	6.110	31.82	6.124	-5.452	39.4	8.5

Table T8. Least Squares Analysis of the Tidal Currents for the O1 Constituent

Series		Major	Minor	Tilt	Phase
Broad Sound	- Winter 1990	0.90	0.08	41.0	345.6
@ 5 m	- Spring 1991	0.62	-0.10	68.7	292.8
Broad Sound	- Spring 1990	0.35	-0.02	27.3	295.6
@ 18 m	- Summer 1990	0.32	-0.03	15.9	288.7
	- Fall 1990	0.56	0.15	-2.1	280.5
	- Winter 1990	0.39	-0.12	65.4	253.4
Boston Buoy	- Winter 1989	0.70	-0.25	89.6	271.9
@ 5 m	- Spring 1990	0.70	-0.09	80.6	297.4
	- Summer 1990	0.93	-0.17	81.5	267.4
	- Winter 1990	0.44	-0.14	-88.8	121.2
	- Spring 1991	0.91	-0.36	19.8	287.2
	- Summer 1991	1.11	0.02	-59.2	89.6
Boston Buoy	- Winter 1989	0.49	-0.05	76.7	313.7
@ 23 m	- Spring 1990	0.46	-0.03	-80.5	61.0
	- Summer 1990	0.40	-0.03	-87.0	114.5
	- Fall 1990	0.84	0.00	86.0	255.2
	- Spring 1991	0.53	0.18	-56.1	48.4
	- Summer 1991	0.49	-0.23	73.1	249.6
Boston Buoy	- Spring 1990	0.70	0.09	-83.3	40.3
@ 33 m	- Summer 1990	0.25	-0.06	67.5	315.3
	- Winter 1990	0.29	-0.07	87.6	278.3
	- Spring 1991	0.39	0.04	-65.7	12.0
	- Summer 1991	0.13	-0.07	7.1	237.5
Manomet Point	- Fall 1990	0.48	0.26	49.0	274.4
@ 5 m	- Winter 1990	0.58	-0.14	-8.1	307.1
	- Spring 1991	0.71	0.00	-3.3	300.3
Manomet Point	- Fall 1990	0.45	0.36	84.0	203.3
@ 29 m	- Winter 1990	0.53	0.14	9.2	270.4
	- Spring 1991	0.54	0.02	10.5	287.6
Race Point	- Fall 1990	1.44	0.61	-16.2	330.5
@ 5 m	- Winter 1990	1.93	0.37	43.6	278.1
	- Spring 1991	2.24	0.01	55.7	239.0
Race Point	- Fall 1990	2.61	0.00	77.6	239.1
@ 23 m	- Winter 1990	1.26	-0.15	62.4	271.1
Race Point	- Fall 1990	2.06	-0.30	42.4	262.3
@ 55 m	- Winter 1990	1.30	0.18	61.9	252.6
	- Spring 1991	1.04	0.29	78.1	242.1
Race Point	- Winter 1990	1.49	0.28	-85.8	59.3
@ 60 m	- Spring 1991	0.78	0.21	86.5	239.8

Scituate	- Summer 1990	1.16	-0.43	-82.1	96.0
@ 5 m	- Fall 1990	0.81	0.49	-42.2	69.9
	- Winter 1990	0.30	0.04	81.9	294.0
	- Spring 1991	0.70	0.12	-23.7	312.9
Scituate	- Spring 1990	0.39	0.06	-79.2	68.4
@ 23 m	- Summer 1990	0.30	0.14	-34.1	325.5
	- Spring 1991	0.75	0.04	89.4	254.2
Stellwagen Basin	- Fall 1990	1.37	0.22	-79.3	18.1
@ 75 m	- Winter 1990	0.82	0.18	-74.7	58.3
	- Spring 1991	0.96	0.29	-69.6	37.4
Stellwagen Basin	- Fall 1990	0.97	0.21	-87.6	20.2
@ 84 m	- Winter 1990	0.49	0.24	85.1	241.1
	- Spring 1991	0.89	0.04	-70.7	20.2
North Channel	- Summer 1990	2.26	-0.99	-42.8	65.0
@ 4 m	- Fall 1990	1.51	-0.48	3.3	54.5
	- Winter 1990	0.76	0.50	29.0	346.0
North Channel	- Spring 1990	0.92	0.05	-69.4	53.9
@ 25 m	- Summer 1990	0.47	0.00	71.0	336.2
	- Winter 1990	1.15	0.25	67.0	27.9
	- Spring 1991	0.57	0.05	56.4	293.1
North Channel	- Summer 1990	0.75	0.01	67.5	344.6
@ 60 m	- Fall 1990	0.62	0.22	51.4	358.8
	- Winter 1990	1.21	0.36	33.2	353.7
	- Spring 1991	0.94	0.32	36.7	7.7
Stellwagen Bank	- Summer 1990	1.65	-0.93	-89.6	140.9
@ 4 m	- Fall 1990	1.18	0.43	83.7	333.1
	- Winter 1990	0.73	-0.09	60.4	309.9
	- Spring 1991	1.37	-0.07	1.5	352.0
Stellwagen Bank	- Summer 1990	1.21	0.07	25.0	154.6
@ 25 m	- Fall 1990	0.89	0.17	47.7	111.5
	- Winter 1990	0.55	0.04	27.3	139.5
	- Spring 1991	0.82	-0.10	22.3	152.8
Stellwagen Basin	- Spr 1990	1.34	0.38	32.7	207.4
@ 8 m	- Summer 1990	0.73	0.00	52.5	166.6
	- Fall 1990	0.75	-0.01	58.4	281.9
	- Winter 1990	0.23	0.06	-34.5	7.8
	- Spring 1991	1.21	0.17	15.9	333.5
Stellwagen Basin	- Spr 1990	1.35	-0.48	12.6	169.5
@ 28 m	- Summer 1990	0.72	-0.20	42.6	199.7
	- Fall 1990	0.51	-0.18	75.5	322.3
	- Winter 1990	0.60	0.12	-68.6	98.4
	- Spring 1991	0.92	0.09	-1.8	345.8

Stellwagen Basin	- Spr 1990	1.36	0.40	-77.5	278.9
@ 72 m	- Summer 1990	0.61	0.31	-89.1	277.1
	- Fall 1990	0.98	0.10	87.2	242.2
	- Winter 1990	1.03	0.15	87.0	282.1
	- Spring 1991	1.13	0.35	-75.5	57.0
Cap Cod Bay	- Spring 1990	1.03	-0.27	-22.9	346.6
@ 4 m	- Summer 1990	0.59	-0.17	-55.6	353.5
	- Fall 1990	1.37	-0.01	-46.9	332.3
	- Winter 1990	0.63	-0.15	20.4	299.4
Cap Cod Bay	- Spring 1990	0.52	-0.06	7.8	250.1
@ 25 m	- Spring 1991	0.47	0.27	5.6	303.9

Table T9. Least Squares Analysis of the Tidal Currents for the K1 Constituent

Series		Major	Minor	Tilt	Phase
Broad Sound	- Winter 1990	1.29	-0.39	29.5	313.8
@ 5 m	- Spring 1991	0.78	0.28	-243.9	85.1
Broad Sound	- Spring 1990	1.22	0.15	-265.3	298.9
@ 18 m	- Summer 1990	0.37	0.28	-240.5	296.9
	- Fall 1990	0.75	0.30	-201.2	49.6
	- Winter 1990	0.47	-0.12	38.1	282.7
Boston Buoy	- Winter 1989	0.47	0.03	-189.5	102.7
@ 5 m	- Spring 1990	1.64	-0.70	-208.1	26.6
	- Summer 1990	1.27	-0.79	-240.7	89.3
	- Winter 1990	0.50	-0.11	11.4	295.3
	- Spring 1991	2.49	-1.62	80.5	110.2
	- Summer 1991	2.04	-1.11	-224.0	91.4
Boston Buoy	- Winter 1989	0.56	0.01	14.0	281.4
@ 23 m	- Spring 1990	1.26	-0.62	4.7	318.3
	- Summer 1990	0.53	-0.13	58.7	316.0
	- Fall 1990	1.17	-0.24	-267.6	34.4
	- Spring 1991	1.29	-0.74	21.1	326.5
	- Summer 1991	0.60	-0.17	51.3	305.9
Boston Buoy	- Spring 1990	1.05	-0.49	-191.9	160.0
@ 33 m	- Summer 1990	0.24	0.02	-261.2	316.8
	- Winter 1990	0.35	0.04	38.9	281.5
	- Spring 1991	0.62	-0.32	-206.5	224.7
	- Summer 1991	0.17	-0.02	-255.3	297.3
Manomet Point	- Fall 1990	2.63	-0.64	47.9	293.1
@ 5 m	- Winter 1990	0.69	-0.03	84.5	291.3
	- Spring 1991	1.89	-1.65	22.8	141.4
Manomet Point	- Fall 1990	0.81	-0.53	-214.0	357.3
@ 29 m	- Winter 1990	0.58	-0.01	-261.3	303.3
	- Spring 1991	1.69	-0.24	65.2	305.0
Race Point	- Fall 1990	5.84	-1.76	26.0	300.0
@ 5 m	- Winter 1990	2.42	-0.23	38.3	285.7
	- Spring 1991	2.09	1.65	-262.8	26.4
Race Point	- Fall 1990	1.27	0.02	-197.9	46.1
@ 23 m	- Winter 1990	1.86	0.07	39.7	275.5
Race Point	- Fall 1990	3.69	0.45	35.9	257.4
@ 55 m	- Winter 1990	1.81	0.27	29.0	274.3
	- Spring 1991	2.56	-0.60	22.8	303.5
Race Point	- Winter 1990	1.09	0.00	-182.7	93.5
@ 60 m	- Spring 1991	1.78	-0.32	7.6	304.3

Scituate @ 5 m	- Summer 1990	1.02	-0.17	-183.6	78.8
	- Fall 1990	2.18	-0.42	44.4	299.4
	- Winter 1990	0.44	-0.10	82.5	297.1
	- Spring 1991	2.12	-1.66	82.4	122.3
Scituate @ 23 m	- Spring 1990	0.94	-0.16	51.2	329.8
	- Summer 1990	0.39	-0.23	31.8	344.3
	- Spring 1991	0.92	-0.61	10.4	19.2
Stellwagen Basin @ 75 m	- Fall 1990	1.41	0.38	-204.0	57.8
	- Winter 1990	0.81	0.46	1.0	270.0
	- Spring 1991	0.82	0.28	5.2	283.9
Stellwagen Basin @ 84 m	- Fall 1990	1.10	0.28	-191.7	76.2
	- Winter 1990	0.47	0.43	29.2	283.4
	- Spring 1991	0.59	0.41	-190.1	111.2
North Channel @ 4 m	- Summer 1990	4.25	-1.97	-199.4	108.7
	- Fall 1990	5.00	-3.01	27.6	318.4
	- Winter 1990	0.79	-0.57	40.8	331.6
North Channel @ 25 m	- Spring 1990	2.27	-0.91	41.7	352.8
	- Summer 1990	0.82	-0.20	48.9	336.2
	- Winter 1990	0.54	-0.28	-261.8	23.8
	- Spring 1991	1.93	-0.70	47.4	3.1
North Channel @ 60 m	- Summer 1990	0.50	0.06	41.6	9.2
	- Fall 1990	1.14	0.08	88.3	67.9
	- Winter 1990	0.52	0.25	-255.5	67.5
	- Spring 1991	1.94	-1.13	-187.3	158.5
Stellwagen Bank @ 4 m	- Summer 1990	4.40	-3.12	-202.0	102.0
	- Fall 1990	4.46	-3.00	19.0	311.0
	- Winter 1990	0.90	-0.06	55.2	313.3
	- Spring 1991	4.82	-2.43	-266.8	89.1
Stellwagen Bank @ 25 m	- Summer 1990	1.45	-0.08	66.8	167.1
	- Fall 1990	1.98	-0.39	83.6	210.0
	- Winter 1990	0.81	-0.05	72.7	133.3
	- Spring 1991	1.75	-0.27	26.8	131.7
Stellwagen Basin @ 8 m	- Spr 1990	1.70	-0.38	-193.5	291.0
	- Summer 1990	1.07	-0.10	61.2	165.5
	- Fall 1990	1.24	-0.20	68.5	326.7
	- Winter 1990	0.69	-0.06	56.1	314.1
	- Spring 1991	1.11	0.47	-249.7	18.2
Stellwagen Basin @ 28 m	- Spr 1990	2.52	-1.78	38.7	173.9
	- Summer 1990	1.10	-0.37	62.9	172.0
	- Fall 1990	1.80	-0.57	-266.3	354.6
	- Winter 1990	0.75	0.05	46.9	297.4
	- Spring 1991	1.40	0.00	40.4	323.1

Stellwagen Basin	- Spr 1990	1.80	-0.05	3.1	127.9
@ 72 m	- Summer 1990	0.87	0.41	12.8	117.9
	- Fall 1990	0.87	0.27	-202.8	67.7
	- Winter 1990	0.65	0.51	48.5	310.1
	- Spring 1991	1.53	0.39	-180.3	96.3
Cap Cod Bay	- Spring 1990	1.98	-0.89	24.0	153.2
@ 4 m	- Summer 1990	2.05	-0.82	0.2	198.3
	- Fall 1990	2.75	-0.55	55.4	279.4
	- Winter 1990	0.94	-0.05	83.9	281.4
Cap Cod Bay	- Spring 1990	1.84	-1.03	70.9	285.8
@ 25 m	- Spring 1991	1.80	-1.03	83.2	289.1

Table T10. Least Squares Analysis of the Tidal Currents for N2 Constituent

Series		Major	Minor	Tilt	Phase
Broad Sound	- Winter 1990	4.39	0.28	46.1	181.4
@ 5 m	- Spring 1991	3.81	-0.38	51.9	201.2
Broad Sound	- Spring 1990	2.44	0.51	82.5	117.2
@ 18 m	- Summer 1990	2.53	0.58	-70.2	280.0
	- Fall 1990	1.69	0.64	68.4	136.0
	- Winter 1990	2.89	0.48	67.9	151.1
Boston Buoy	- Winter 1989	1.88	0.05	78.1	143.6
@ 5 m	- Spring 1990	1.62	-0.60	84.6	156.1
	- Summer 1990	2.45	-0.63	-56.8	281.9
	- Winter 1990	2.63	-0.16	77.0	168.4
	- Spring 1991	2.73	-0.38	84.7	179.7
	- Summer 1991	1.76	0.43	-46.2	291.2
Boston Buoy	- Winter 1989	1.83	0.02	89.2	152.1
@ 23 m	- Spring 1990	2.33	-0.35	83.2	173.4
	- Summer 1990	2.48	-0.36	81.3	171.1
	- Fall 1990	3.29	-1.38	84.1	168.2
	- Spring 1991	1.62	0.17	83.5	171.2
	- Summer 1991	3.08	-0.04	87.6	160.9
Boston Buoy	- Spring 1990	1.68	0.19	-80.7	334.5
@ 33 m	- Summer 1990	1.54	0.07	-71.3	332.3
	- Winter 1990	1.80	0.20	76.4	151.9
	- Spring 1991	1.09	0.12	69.7	149.0
	- Summer 1991	2.48	-0.11	-82.5	327.3
Manomet Point	- Fall 1990	2.75	-0.34	1.9	188.2
@ 5 m	- Winter 1990	2.89	0.13	-3.1	174.7
	- Spring 1991	2.82	-0.47	-8.0	197.6
Manomet Point	- Fall 1990	1.94	0.19	-3.8	194.6
@ 29 m	- Winter 1990	3.09	0.07	-1.0	167.7
	- Spring 1991	2.60	0.19	4.0	176.5
Race Point	- Fall 1990	9.36	0.44	55.3	182.1
@ 5 m	- Winter 1990	10.55	0.17	58.9	164.8
	- Spring 1991	7.35	-0.17	58.8	171.9
Race Point	- Fall 1990	9.67	-3.04	54.7	177.6
@ 23 m	- Winter 1990	10.30	-0.39	55.1	172.1
Race Point	- Fall 1990	6.83	1.44	65.5	157.1
@ 55 m	- Winter 1990	9.34	-0.45	60.2	155.3
	- Spring 1991	6.92	0.98	56.5	155.3
Race Point	- Winter 1990	6.17	0.74	63.5	135.5
@ 60 m	- Spring 1991	4.84	0.41	65.8	155.5

Scituate	- Summer 1990	3.27	-0.21	59.3	158.8
@ 5 m	- Fall 1990	2.02	-0.47	55.4	167.5
	- Winter 1990	1.82	0.36	46.3	167.4
	- Spring 1991	2.31	-0.01	49.2	169.2
Scituate	- Spring 1990	1.24	-0.17	54.8	147.3
@ 23 m	- Summer 1990	1.43	0.56	-84.7	213.8
	- Spring 1991	1.08	0.32	-56.9	201.6
Stellwagen Basin	- Fall 1990	4.79	-0.09	-54.9	301.5
@ 75 m	- Winter 1990	2.98	-0.07	78.7	161.2
	- Spring 1991	2.54	-0.47	-62.2	315.1
Stellwagen Basin	- Fall 1990	2.95	0.29	-53.5	292.9
@ 84 m	- Winter 1990	1.77	0.30	87.6	147.5
	- Spring 1991	1.89	-0.40	-44.1	313.2
North Channel	- Summer 1990	2.81	0.14	-86.1	19.8
@ 4 m	- Fall 1990	2.72	-1.31	83.2	235.9
	- Winter 1990	2.31	0.35	76.9	212.0
North Channel	- Spring 1990	2.69	0.31	-78.3	1.0
@ 25 m	- Summer 1990	1.81	0.61	-58.8	351.8
	- Winter 1990	3.41	1.21	69.7	217.5
	- Spring 1991	2.27	0.35	84.1	207.7
North Channel	- Summer 1990	2.93	-0.75	84.0	223.7
@ 60 m	- Fall 1990	2.06	1.11	-40.4	347.5
	- Winter 1990	2.12	0.79	85.2	203.7
	- Spring 1991	2.54	1.40	-71.7	31.9
Stellwagen Bank	- Summer 1990	6.14	-4.01	86.3	206.7
@ 4 m	- Fall 1990	4.80	-1.05	79.2	216.2
	- Winter 1990	3.18	-0.17	60.0	226.0
	- Spring 1991	6.16	-0.92	66.7	218.6
Stellwagen Bank	- Summer 1990	3.32	0.29	51.7	10.3
@ 25 m	- Fall 1990	4.05	0.12	60.4	17.5
	- Winter 1990	3.40	-0.26	60.4	10.8
	- Spring 1991	2.01	0.42	77.0	1.9
Stellwagen Basin	- Spr 1990	3.75	0.04	42.5	309.6
@ 8 m	- Summer 1990	2.67	0.18	29.9	318.1
	- Fall 1990	0.62	-0.22	18.4	198.6
	- Winter 1990	3.02	0.35	72.1	183.3
	- Spring 1991	2.88	-0.14	45.2	241.6
Stellwagen Basin	- Spr 1990	3.65	0.47	62.6	298.5
@ 28 m	- Summer 1990	2.18	1.24	49.0	303.7
	- Fall 1990	1.78	-0.56	14.8	159.6
	- Winter 1990	3.15	0.63	69.9	196.0
	- Spring 1991	2.09	0.48	31.5	248.2

Stellwagen Basin	- Spr 1990	4.36	-0.05	-85.2	80.0
@ 72 m	- Summer 1990	2.94	-0.06	-85.4	73.9
	- Fall 1990	0.97	0.04	-68.0	285.7
	- Winter 1990	3.14	0.34	71.2	194.8
	- Spring 1991	3.17	-0.13	-85.1	357.7
Cap Cod Bay	- Spring 1990	4.25	0.13	-21.5	222.1
@ 4 m	- Summer 1990	3.54	1.12	7.5	179.6
	- Fall 1990	3.17	-0.19	-7.8	208.1
	- Winter 1990	3.59	0.55	-3.1	212.9
Cap Cod Bay	- Spring 1990	4.78	-0.44	-16.5	216.4
@ 25 m	- Spring 1991	3.34	-0.23	-15.0	211.8

Table T11. Least Squares Analysis of the Tidal Currents for M2 Constituent

Series		Major	Minor	Tilt	Phase
Broad Sound	- Winter 1990	16.11	1.41	49.7	219.8
@ 5 m	- Spring 1991	16.14	-0.27	52.9	217.7
Broad Sound	- Spring 1990	9.21	3.61	83.4	163.9
@ 18 m	- Summer 1990	9.48	4.12	89.7	155.8
	- Fall 1990	9.35	3.13	81.8	168.7
	- Winter 1990	9.96	1.26	65.9	188.6
Boston Buoy	- Winter 1989	9.43	-0.66	77.1	204.0
@ 5 m	- Spring 1990	7.40	-1.01	84.4	198.8
	- Summer 1990	5.35	1.26	-82.0	352.3
	- Winter 1990	9.85	-0.98	76.9	203.9
	- Spring 1991	9.14	-0.15	74.5	196.1
	- Summer 1991	5.44	1.80	-85.8	0.6
Boston Buoy	- Winter 1989	9.10	-0.30	87.1	196.6
@ 23 m	- Spring 1990	7.67	0.36	86.7	200.0
	- Summer 1990	10.19	-0.47	82.1	206.9
	- Fall 1990	11.03	-0.17	87.1	199.8
	- Spring 1991	9.66	-0.28	85.3	203.0
	- Summer 1991	11.22	-0.79	80.3	208.3
Boston Buoy	- Spring 1990	7.01	0.99	-87.3	353.3
@ 33 m	- Summer 1990	8.78	0.42	-76.8	1.3
	- Winter 1990	6.69	0.59	77.0	185.1
	- Spring 1991	7.92	0.56	78.9	179.9
	- Summer 1991	7.94	-0.13	-88.4	1.2
Manomet Point	- Fall 1990	13.39	-1.06	-1.8	212.1
@ 5 m	- Winter 1990	11.26	0.03	-4.9	211.1
	- Spring 1991	13.54	-0.97	-9.3	215.0
Manomet Point	- Fall 1990	7.25	1.27	-1.1	208.6
@ 29 m	- Winter 1990	10.61	0.64	-1.3	207.3
	- Spring 1991	13.28	0.96	4.1	202.2
Race Point	- Fall 1990	46.31	-4.12	63.1	197.1
@ 5 m	- Winter 1990	40.81	3.28	54.3	200.2
	- Spring 1991	45.24	2.18	51.7	202.0
Race Point	- Fall 1990	44.87	-5.36	57.6	197.5
@ 23 m	- Winter 1990	43.47	-1.07	53.1	201.4
Race Point	- Fall 1990	39.30	9.78	54.1	195.0
@ 55 m	- Winter 1990	42.63	0.37	62.0	189.1
	- Spring 1991	41.64	1.29	62.9	184.3
Race Point	- Winter 1990	30.11	0.46	67.9	184.0
@ 60 m	- Spring 1901	25.60	2.02	70.2	177.3

Scituate @ 5 m	- Summer 1990	10.64	-1.38	79.0	173.4
	- Fall 1990	9.05	-0.38	56.0	196.0
	- Winter 1990	7.80	1.21	45.6	202.9
	- Spring 1991	9.55	0.46	48.4	202.7
Scituate @ 23 m	- Spring 1990	2.31	1.66	-33.4	237.1
	- Summer 1990	3.49	1.51	-29.7	236.2
	- Spring 1991	4.25	1.28	-65.2	258.9
Stellwagen Basin @ 75 m	- Fall 1990	20.00	-0.98	-59.7	335.0
	- Winter 1990	13.49	0.87	-88.3	9.9
	- Spring 1991	15.75	-1.74	-76.2	354.8
Stellwagen Basin @ 84 m	- Fall 1990	11.80	1.37	-57.5	328.0
	- Winter 1990	7.94	1.64	-84.6	356.9
	- Spring 1991	9.90	0.52	-64.0	344.0
North Channel @ 4 m	- Summer 1990	6.92	2.46	79.4	230.2
	- Fall 1990	9.63	1.78	82.3	230.7
	- Winter 1990	8.28	1.46	78.6	232.5
North Channel @ 25 m	- Spring 1990	11.60	0.79	-87.0	39.9
	- Summer 1990	10.55	0.72	-86.2	47.7
	- Winter 1990	13.90	2.08	-89.5	50.1
	- Spring 1991	10.57	1.39	88.0	228.3
North Channel @ 60 m	- Summer 1990	10.49	2.38	-83.9	52.3
	- Fall 1990	9.35	4.02	-79.8	56.1
	- Winter 1990	11.21	2.86	84.3	237.4
	- Spring 1991	13.79	2.97	77.0	236.4
Stellwagen Bank @ 4 m	- Summer 1990	23.37	-9.98	83.1	238.0
	- Fall 1990	20.00	-5.24	79.1	227.3
	- Winter 1990	15.36	-1.27	68.6	231.7
	- Spring 1991	29.00	-4.58	71.5	229.9
Stellwagen Bank @ 25 m	- Summer 1990	22.73	1.08	50.1	45.2
	- Fall 1990	16.55	-0.13	51.3	45.0
	- Winter 1990	13.92	-0.16	61.3	42.7
	- Spring 1991	14.98	1.75	66.5	42.0
Stellwagen Basin @ 8 m	- Spr 1990	16.89	-0.45	41.3	321.3
	- Summer 1990	15.61	0.57	39.8	335.7
	- Fall 1990	12.48	-0.80	37.8	258.7
	- Winter 1990	9.68	2.62	72.6	221.3
	- Spring 1991	13.05	2.22	44.6	249.4
Stellwagen Basin @ 28 m	- Spr 1990	10.38	5.98	50.9	313.1
	- Summer 1990	10.53	5.79	54.8	323.3
	- Fall 1990	11.93	0.70	45.2	244.7
	- Winter 1990	12.16	3.20	74.4	220.4
	- Spring 1991	10.51	5.23	56.3	237.7

Stellwagen Basin	- Spr 1990	16.82	0.49	-83.8	84.5
@ 72 m	- Summer 1990	17.20	-1.08	-80.5	100.6
	- Fall 1990	15.59	0.43	-75.0	10.9
	- Winter 1990	13.64	1.54	78.2	211.4
	- Spring 1991	16.56	-0.83	-87.4	18.2
Cap Cod Bay	- Spring 1990	17.75	-0.27	-14.2	230.9
@ 4 m	- Summer 1990	17.00	1.08	8.7	210.7
	- Fall 1990	15.25	0.79	-1.4	221.9
	- Winter 1990	13.45	-0.24	-4.3	222.6
Cap Cod Bay	- Spring 1990	17.06	-0.23	-10.9	228.8
@ 25 m	- Spring 1991	16.45	-0.06	-15.8	229.0

Table T12. Least Squares Analysis of the Tidal Currents for S2 Constituent

Series		Major	Minor	Tilt	Phase
Broad Sound @ 5 m	- Winter 1990	4.29	1.10	39.1	264.7
	- Spring 1991	2.48	0.39	37.7	272.9
Broad Sound @ 18 m	- Spring 1990	1.00	0.23	10.4	213.5
	- Summer 1990	1.77	0.38	-181.2	4.6
	- Fall 1990	1.65	0.12	6.3	213.8
	- Winter 1990	1.84	0.00	24.0	207.6
Boston Buoy @ 5 m	- Winter 1989	1.56	0.10	16.5	224.7
	- Spring 1990	0.81	-0.22	-198.3	99.1
	- Summer 1990	1.80	-0.66	-183.9	331.7
	- Winter 1990	2.18	-0.32	10.5	226.3
	- Spring 1991	1.41	0.28	7.9	245.9
	- Summer 1991	0.79	-0.34	-218.0	18.4
Boston Buoy @ 23 m	- Winter 1989	1.79	-0.01	6.4	226.2
	- Spring 1990	1.04	-0.06	-186.5	47.4
	- Summer 1990	1.32	-0.01	12.7	221.8
	- Fall 1990	1.99	-0.24	10.6	236.8
	- Spring 1991	1.47	-0.32	12.8	249.5
	- Summer 1991	1.85	-0.36	10.5	233.1
Boston Buoy @ 33 m	- Spring 1990	1.32	0.15	-205.1	14.5
	- Summer 1990	1.30	0.01	4.5	218.1
	- Winter 1990	1.34	0.19	18.3	219.4
	- Spring 1991	1.13	0.22	6.3	223.6
	- Summer 1991	1.12	-0.01	6.9	215.3
Manomet Point @ 5 m	- Fall 1990	1.62	0.02	88.7	248.6
	- Winter 1990	2.11	0.34	-266.6	237.6
	- Spring 1991	1.93	-0.17	-251.9	274.5
Manomet Point @ 29 m	- Fall 1990	1.19	-0.01	88.3	250.6
	- Winter 1990	2.07	0.13	89.2	231.4
	- Spring 1991	2.21	-0.10	87.7	250.0
Race Point @ 5 m	- Fall 1990	6.66	-1.05	28.9	234.3
	- Winter 1990	8.19	-0.74	24.2	224.7
	- Spring 1991	7.04	-1.45	18.0	244.3
Race Point @ 23 m	- Fall 1990	4.72	-0.26	38.2	243.1
	- Winter 1990	7.16	-0.04	37.1	223.8
Race Point @ 55 m	- Fall 1990	4.69	-0.05	20.9	213.5
	- Winter 1990	7.28	0.32	19.7	274.6
	- Spring 1991	5.10	1.31	44.2	241.0
Race Point @ 60 m	- Winter 1990	7.50	-0.12	33.7	225.0
	- Spring 1991	3.53	0.59	35.4	242.1

Scituate	- Summer 1990	2.06	0.13	59.9	293.9
@ 5 m	- Fall 1990	0.81	0.46	-183.2	55.9
	- Winter 1990	1.36	0.53	31.1	227.7
	- Spring 1991	1.20	0.60	9.5	206.3
Scituate	- Spring 1990	0.82	-0.13	-204.3	330.4
@ 23 m	- Summer 1990	1.09	-0.03	23.8	196.9
	- Spring 1991	0.81	-0.65	-207.3	182.0
Stellwagen Basin	- Fall 1990	2.71	-0.13	-213.6	19.9
@ 75 m	- Winter 1990	2.56	0.75	11.1	229.9
	- Spring 1991	1.89	0.40	10.6	241.6
Stellwagen Basin	- Fall 1990	1.52	0.26	-214.4	9.3
@ 84 m	- Winter 1990	1.74	0.67	10.5	220.2
	- Spring 1991	1.39	0.43	3.2	235.2
North Channel	- Summer 1990	2.23	0.39	83.1	274.1
@ 4 m	- Fall 1990	0.70	0.57	13.3	255.7
	- Winter 1990	1.91	-0.07	-189.6	45.9
North Channel	- Spring 1990	1.83	0.24	80.6	339.5
@ 25 m	- Summer 1990	1.75	-0.32	-183.4	49.8
	- Winter 1990	2.66	0.63	-192.1	53.5
	- Spring 1991	2.56	-0.13	10.4	270.1
North Channel	- Summer 1990	3.06	-0.56	-181.3	56.6
@ 60 m	- Fall 1990	1.67	0.15	-193.7	61.6
	- Winter 1990	2.78	0.91	-181.4	52.4
	- Spring 1991	1.98	0.50	0.2	261.0
Stellwagen Bank	- Summer 1990	6.35	-4.36	-190.6	32.3
@ 4 m	- Fall 1990	3.29	-1.10	12.9	254.8
	- Winter 1990	3.46	-0.40	20.4	225.0
	- Spring 1991	3.67	0.21	17.3	261.1
Stellwagen Bank	- Summer 1990	5.24	0.52	43.1	45.9
@ 25 m	- Fall 1990	2.26	0.14	42.7	56.2
	- Winter 1990	2.86	-0.22	38.1	50.7
	- Spring 1991	2.48	0.18	17.9	61.4
Stellwagen Basin	- Spr 1990	1.81	-0.61	41.8	327.4
@ 8 m	- Summer 1990	2.26	0.32	40.7	318.4
	- Fall 1990	0.82	-0.05	80.5	334.3
	- Winter 1990	2.00	1.10	14.5	225.3
	- Spring 1991	1.74	0.09	25.4	255.9
Stellwagen Basin	- Spr 1990	1.66	-0.17	67.7	4.4
@ 28 m	- Summer 1990	1.96	0.81	55.9	342.2
	- Fall 1990	0.93	0.14	29.6	270.6
	- Winter 1990	2.71	1.39	34.7	241.5
	- Spring 1991	1.78	0.20	14.2	252.2

Stellwagen Basin @ 72 m	- Spr 1990	1.61	-0.22	11.4	259.5
	- Summer 1990	2.70	-0.28	0.7	260.7
	- Fall 1990	1.24	0.10	-199.0	84.2
	- Winter 1990	2.71	1.04	24.4	231.6
	- Spring 1991	1.73	0.38	8.9	224.2
Cap Cod Bay @ 4 m	- Spring 1990	2.50	-0.71	-269.0	253.2
	- Summer 1990	2.51	0.01	80.3	217.8
	- Fall 1990	2.20	-0.38	85.9	226.8
	- Winter 1990	1.97	0.46	-260.9	230.9
Cap Cod Bay @ 25 m	- Spring 1990	1.71	0.55	89.8	236.8
	- Spring 1991	2.63	-0.06	-262.7	252.8

Table T13. Least Squares Analysis of the Tidal Currents for M4 Constituent

Series		Major	Minor	Incline	Phase
Broad Sound	- Winter 1990	1.64	0.09	20.5	186.3
@ 5 m	- Spring 1991	1.76	-0.23	17.7	171.0
Broad Sound	- Spring 1990	0.74	-0.14	30.4	26.1
@ 18 m	- Summer 1990	0.31	0.24	16.0	7.1
	- Fall 1990	0.56	0.04	-7.5	22.0
	- Winter 1990	0.89	-0.25	19.4	64.4
Boston Buoy	- Winter 1989	0.35	0.10	88.1	98.3
@ 5 m	- Spring 1990	0.40	-0.27	55.4	165.6
	- Summer 1990	1.19	-0.94	78.4	98.6
	- Winter 1990	0.36	0.00	60.7	103.0
	- Spring 1991	0.56	-0.04	-76.6	304.2
	- Summer 1991	0.90	-0.45	86.2	114.9
Boston Buoy	- Winter 1989	0.46	0.19	-68.9	283.2
@ 23 m	- Spring 1990	0.41	-0.19	-53.7	261.0
	- Summer 1990	0.52	-0.05	61.0	151.3
	- Fall 1990	0.43	-0.16	81.6	197.5
	- Summer 1991	0.51	0.31	88.0	132.9
Boston Buoy	- Spring 1990	0.49	-0.22	74.6	31.9
@ 33 m	- Summer 1990	0.62	-0.10	-85.1	289.6
	- Winter 1990	0.33	0.00	87.2	84.6
	- Spring 1991	0.72	-0.19	-75.9	261.9
	- Summer 1991	0.49	0.07	-61.8	265.5
Manomet Point	- Fall 1990	1.10	0.14	-0.2	77.0
@ 5 m	- Winter 1990	0.35	0.06	-9.9	124.3
	- Spring 1991	0.30	0.15	-5.1	168.6
Manomet Point	- Fall 1990	0.51	-0.32	33.9	163.6
@ 29 m	- Winter 1990	0.48	-0.22	-31.4	88.7
	- Spring 1991	0.90	-0.26	-11.6	113.8
Race Point	- Fall 1990	2.63	-0.75	-42.4	172.8
@ 5 m	- Winter 1990	2.21	-0.39	-70.5	203.1
	- Spring 1991	2.68	0.61	-36.4	181.2
Race Point	- Fall 1990	1.86	0.17	-27.8	173.5
@ 23 m	- Winter 1990	2.58	-1.10	-1.7	211.0
Race Point	- Fall 1990	4.65	-2.17	-50.9	337.3
@ 55 m	- Winter 1990	2.99	-2.04	66.5	108.9
	- Spring 1991	3.21	-1.40	-74.4	329.2
Race Point	- Winter 1990	1.88	-1.07	-61.6	319.5
@ 60 m	- Spring 1991	3.00	-0.98	-62.3	322.9

Scituate @ 5 m	- Summer 1990	1.31	-0.53	68.6	142.9
	- Fall 1990	0.30	-0.02	-22.6	147.4
	- Winter 1990	0.28	0.04	37.6	89.4
	- Spring 1991	0.29	-0.12	-16.7	124.4
Scituate @ 23 m	- Spring 1990	0.40	-0.18	-8.2	114.8
	- Summer 1990	0.56	0.05	-72.2	157.8
	- Spring 1991	1.25	0.05	76.8	26.9
Stellwagen Basin @ 75 m	- Fall 1990	1.21	-0.76	-87.6	269.2
	- Winter 1990	0.72	-0.41	-6.9	44.7
	- Spring 1991	0.96	-0.43	-61.8	34.0
Stellwagen Basin @ 84 m	- Fall 1990	0.94	-0.64	79.5	86.7
	- Winter 1990	0.32	-0.29	-1.2	45.9
	- Spring 1991	0.71	-0.49	-78.1	4.1
North Channel @ 4 m	- Summer 1990	2.61	-0.89	-67.5	16.3
	- Fall 1990	0.89	-0.43	55.0	129.3
	- Winter 1990	0.48	0.06	67.9	100.4
North Channel @ 25 m	- Spring 1990	1.50	-0.30	-86.8	255.5
	- Summer 1990	1.35	0.19	81.9	100.3
	- Winter 1990	1.19	-0.34	49.5	137.3
	- Spring 1991	0.85	0.11	80.9	137.9
North Channel @ 60 m	- Summer 1990	0.31	0.02	16.9	201.1
	- Fall 1990	0.49	-0.35	-62.1	131.6
	- Winter 1990	0.45	-0.07	-12.2	158.2
	- Spring 1991	0.72	-0.69	6.7	155.6
Stellwagen Bank @ 4 m	- Summer 1990	2.69	-1.19	78.9	110.4
	- Fall 1990	0.86	0.13	-44.5	289.3
	- Winter 1990	0.95	0.52	-49.1	261.9
	- Spring 1991	2.35	-0.38	50.2	177.6
Stellwagen Bank @ 25 m	- Summer 1990	1.84	0.13	19.8	315.1
	- Fall 1990	1.85	0.21	14.6	323.2
	- Winter 1990	0.76	0.27	28.4	345.4
	- Spring 1991	1.09	-0.10	35.6	292.4
Stellwagen Basin @ 8 m	- Spr 1990	1.86	-1.31	-3.3	79.7
	- Summer 1990	1.11	-0.76	-46.0	50.1
	- Fall 1990	0.74	-0.34	-15.8	283.3
	- Winter 1990	0.29	-0.04	-57.4	296.6
	- Spring 1991	1.11	-0.26	-76.2	268.6
Stellwagen Basin @ 28 m	- Spr 1990	2.00	-1.74	-61.4	98.3
	- Summer 1990	1.39	-0.76	56.8	262.8
	- Fall 1990	1.33	-0.67	-79.3	311.7
	- Winter 1990	0.41	0.05	-62.7	306.2
	- Spring 1991	1.57	-0.53	85.9	121.3

Stellwagen Basin	- Spr 1990	1.07	-0.65	50.2	318.0
@ 72 m	- Summer 1990	0.81	0.41	26.7	106.0
	- Fall 1990	0.76	-0.20	44.0	111.3
	- Winter 1990	0.40	-0.19	-21.6	82.0
	- Spring 1991	0.58	-0.22	-57.0	87.5
Cap Cod Bay	- Spring 1990	0.56	-0.44	-47.2	157.9
@ 4 m	- Summer 1990	0.90	0.05	3.7	116.0
	- Fall 1990	0.62	-0.28	-37.7	193.2
	- Winter 1990	0.86	0.01	36.8	139.1
Cap Cod Bay	- Spring 1990	0.74	-0.08	-20.6	143.1
@ 25 m	- Spring 1991	0.73	-0.22	-86.9	133.3

Table T14. Least Squares Analysis of the Tidal Currents for M6 Constituent

Series		Major	Minor	Incline	Phase
Broad Sound @ 5 m	- Winter 1990	0.69	0.07	23.5	68.2
	- Spring 1991	0.91	0.32	28.0	46.2
Broad Sound @ 18 m	- Spring 1990	0.74	-0.30	72.2	2.6
	- Summer 1990	0.99	-0.28	50.0	16.2
	- Fall 1990	0.79	-0.32	36.8	1.9
	- Winter 1990	0.74	-0.23	44.3	350.3
Boston Buoy @ 5 m	- Winter 1989	0.46	0.10	65.8	347.5
	- Spring 1990	0.39	0.01	86.1	336.8
	- Summer 1990	0.68	-0.27	35.2	9.0
	- Winter 1990	0.47	0.08	59.5	352.8
	- Spring 1991	0.67	0.05	48.4	5.2
	- Summer 1991	0.75	-0.12	40.5	12.1
Boston Buoy @ 23 m	- Winter 1989	0.42	0.10	64.4	343.9
	- Spring 1990	0.34	0.13	59.1	335.4
	- Summer 1990	0.48	0.07	51.7	354.4
	- Fall 1990	0.27	0.00	-65.2	144.9
	- Winter 1990	0.33	0.14	59.9	327.4
	- Spring 1991	0.55	0.13	61.4	327.8
	- Summer 1991	0.30	0.12	73.8	336.0
Boston Buoy @ 33 m	- Spring 1990	0.57	0.11	66.7	340.2
	- Summer 1990	0.56	-0.04	71.0	12.8
	- Winter 1990	0.42	0.09	56.2	350.1
	- Spring 1991	0.69	-0.03	60.2	350.5
Manomet Point @ 5 m	- Fall 1990	1.54	0.09	-8.2	28.0
	- Winter 1990	1.09	0.04	-6.7	10.8
	- Spring 1991	1.33	0.08	-17.3	24.5
Manomet Point @ 29 m	- Fall 1990	1.01	-0.04	-11.4	24.8
	- Winter 1990	1.00	0.04	-12.5	19.1
	- Spring 1991	1.57	-0.06	-6.6	33.4
Race Point @ 5 m	- Fall 1990	2.27	0.51	51.4	18.9
	- Winter 1990	2.51	0.05	67.6	18.0
	- Spring 1991	2.65	0.33	47.4	17.0
Race Point @ 23 m	- Fall 1990	3.96	0.00	52.6	40.4
	- Winter 1990	2.92	0.34	52.6	44.0
Race Point @ 55 m	- Fall 1990	3.38	-0.94	59.0	27.5
	- Winter 1990	3.32	-0.58	53.3	34.8
	- Spring 1991	3.68	-0.93	54.8	36.9
Race Point @ 60 m	- Winter 1990	2.30	-0.26	56.7	0.4
	- Spring 1991	1.97	-0.39	52.7	3.5

Scituate	- Summer 1990	0.70	0.05	21.8	13.4
@ 5 m	- Fall 1990	0.81	0.09	13.6	11.0
	- Winter 1990	0.91	0.01	1.8	12.9
	- Spring 1991	0.95	-0.13	1.6	17.2
Scituate	- Spring 1990	0.33	0.27	-32.5	0.6
@ 23 m	- Summer 1990	0.93	-0.07	4.4	1.9
	- Spring 1991	0.73	-0.01	8.9	356.7
Stellwagen Basin	- Fall 1990	1.55	-0.78	38.0	356.0
@ 75 m	- Winter 1990	0.71	-0.04	35.8	7.4
	- Spring 1991	0.71	0.11	19.5	12.6
Stellwagen Basin	- Fall 1990	1.21	-0.13	41.0	5.7
@ 84 m	- Winter 1990	0.42	0.02	37.2	355.9
	- Spring 1991	0.43	0.09	87.7	306.4
North Channel	- Summer 1990	1.09	0.26	-74.5	214.4
@ 4 m	- Fall 1990	0.53	-0.05	27.8	80.1
	- Winter 1990	0.64	-0.17	27.9	88.4
North Channel	- Spring 1990	0.37	-0.06	28.2	94.4
@ 25 m	- Summer 1990	0.63	-0.20	52.9	86.0
	- Winter 1990	0.91	-0.42	63.7	103.9
	- Spring 1991	0.83	-0.06	58.4	73.4
North Channel	- Summer 1990	1.18	0.00	43.4	98.5
@ 60 m	- Fall 1990	0.85	0.10	61.5	73.6
	- Winter 1990	0.60	-0.08	58.4	84.7
	- Spring 1991	1.19	-0.33	45.9	109.5
Stellwagen Bank	- Summer 1990	2.05	-1.13	58.4	70.5
@ 4 m	- Fall 1990	2.16	-0.73	42.6	76.0
	- Winter 1990	0.90	0.18	33.8	71.6
	- Spring 1991	2.34	-0.18	38.8	96.9
Stellwagen Bank	- Summer 1990	1.69	0.04	11.5	273.9
@ 25 m	- Fall 1990	0.52	0.07	31.2	282.0
	- Winter 1990	1.31	-0.12	34.5	251.1
	- Spring 1991	1.66	-0.08	52.7	246.0
Stellwagen Basin	- Spr 1990	0.38	0.28	-29.2	71.1
@ 8 m	- Summer 1990	0.64	0.13	-31.3	87.3
	- Fall 1990	0.50	0.13	2.7	114.7
	- Winter 1990	0.55	0.00	23.8	68.7
	- Spring 1991	0.61	0.11	42.5	91.2
Stellwagen Basin	- Spr 1990	0.98	-0.33	25.7	331.0
@ 28 m	- Summer 1990	1.17	-0.06	30.1	349.2
	- Fall 1990	0.49	-0.10	32.5	65.0
	- Winter 1990	0.69	-0.12	22.3	76.2
	- Spring 1991	0.87	-0.12	34.6	88.2

Stellwagen Basin @ 72 m	- Spr 1990	1.12	-0.10	28.0	296.3
	- Summer 1990	1.15	-0.35	10.3	336.8
	- Fall 1990	1.07	-0.40	27.2	49.5
	- Winter 1990	0.54	-0.05	9.3	73.6
	- Spring 1991	1.13	-0.15	13.4	84.3
Cap Cod Bay @ 4 m	- Spring 1990	1.44	0.08	-21.8	97.4
	- Summer 1990	1.91	0.09	-16.7	115.6
	- Fall 1990	1.54	0.33	-10.3	98.4
	- Winter 1990	1.21	-0.02	-10.3	63.9
Cap Cod Bay @ 25 m	- Spring 1990	1.67	-0.10	-9.9	97.2
	- Spring 1991	2.01	-0.12	-21.7	103.5

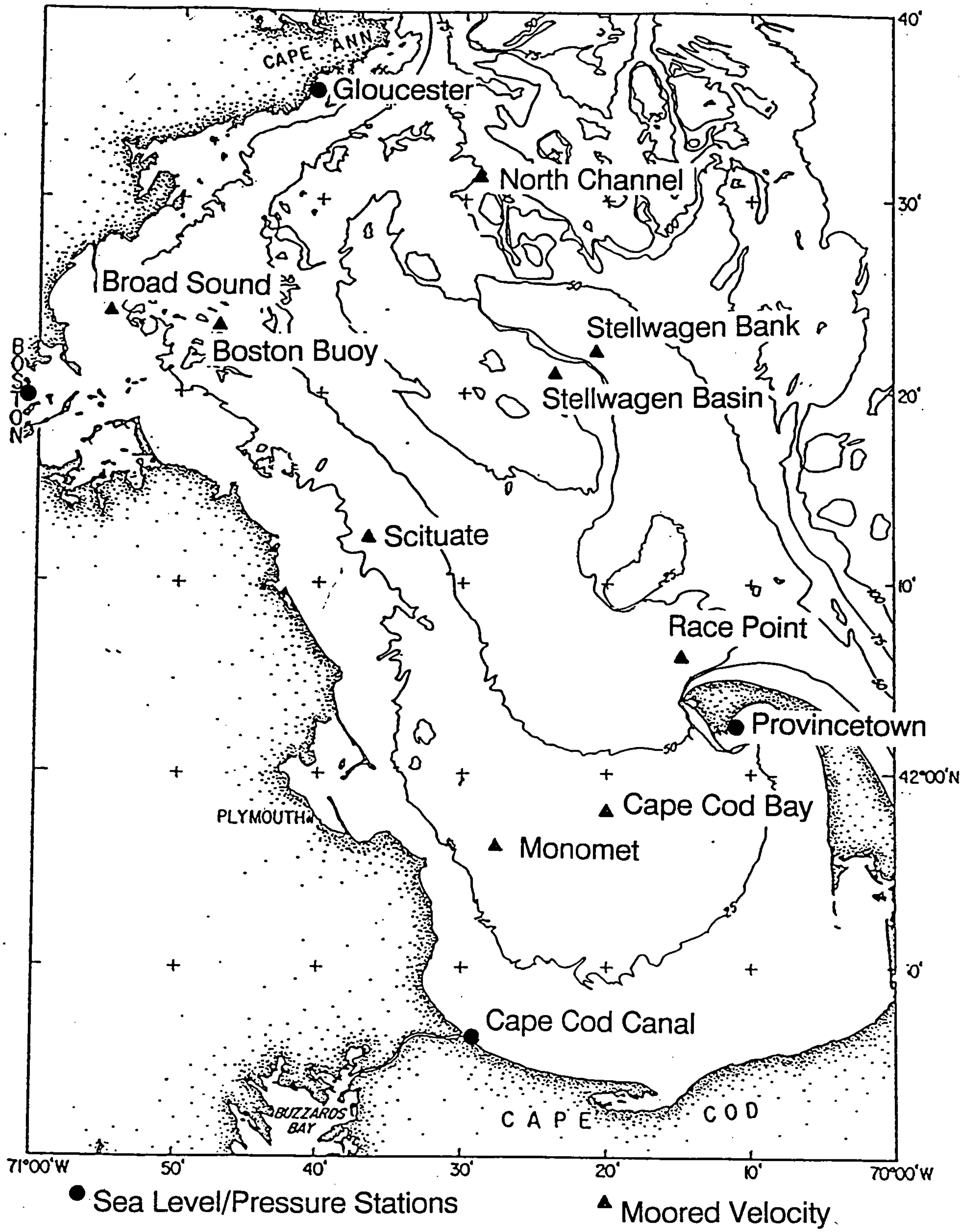
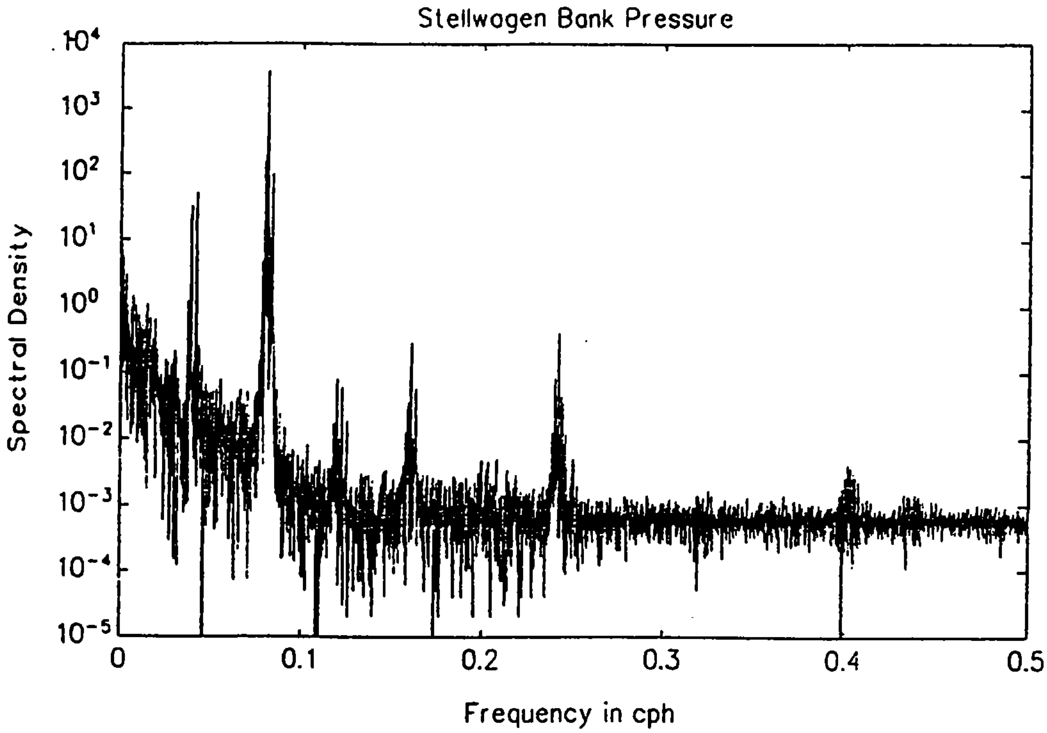


Figure T1 Locations of the bottom pressure, surface elevation, and moored current observations.



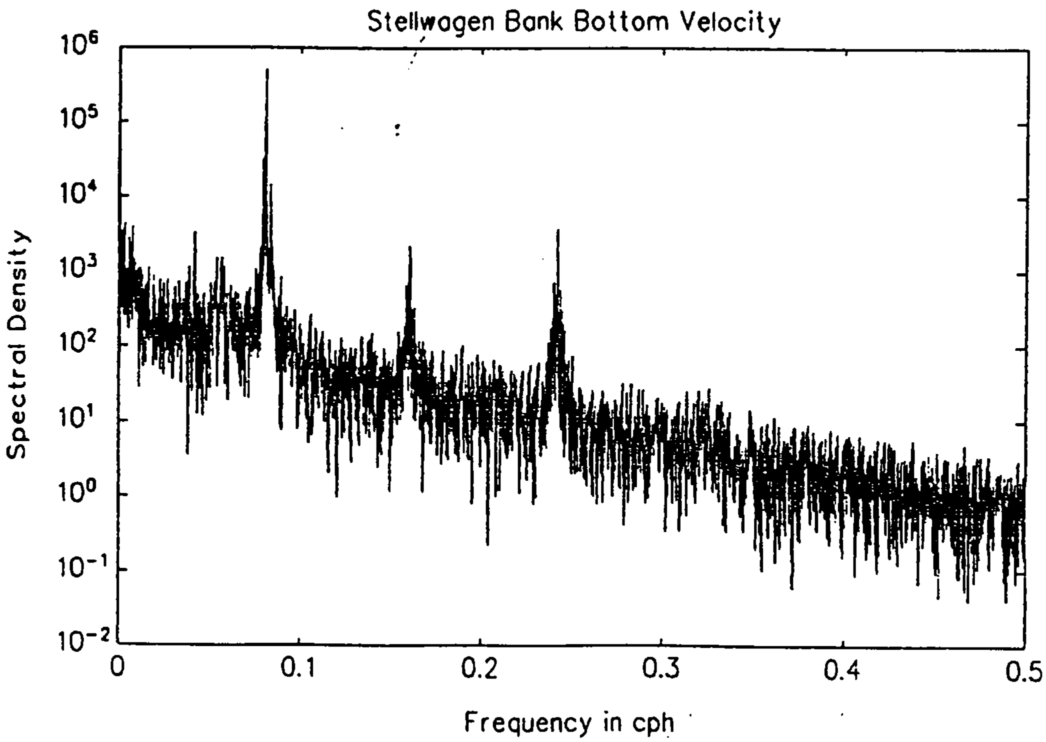


Figure T2 Spectral of the combined data series (7219 hours) taken on Stellwagen Bank — bottom pressure at 29 m (top plot) and velocity at 27 m (bottom plot). The semidiurnal tides (0.08 cph) are the dominate energy in both plots, with the diurnal (0.04 cph), quarterdiurnal (0.16) and hexdiurnal having energy above background sea level fluctuations. In the pressure, the terdiurnal (0.12 cph) is seen and in the currents the inertial frequency (0.056) barely rises above background, and the diurnal signal is only as strong as the quarter, and hexdiurnal tides.

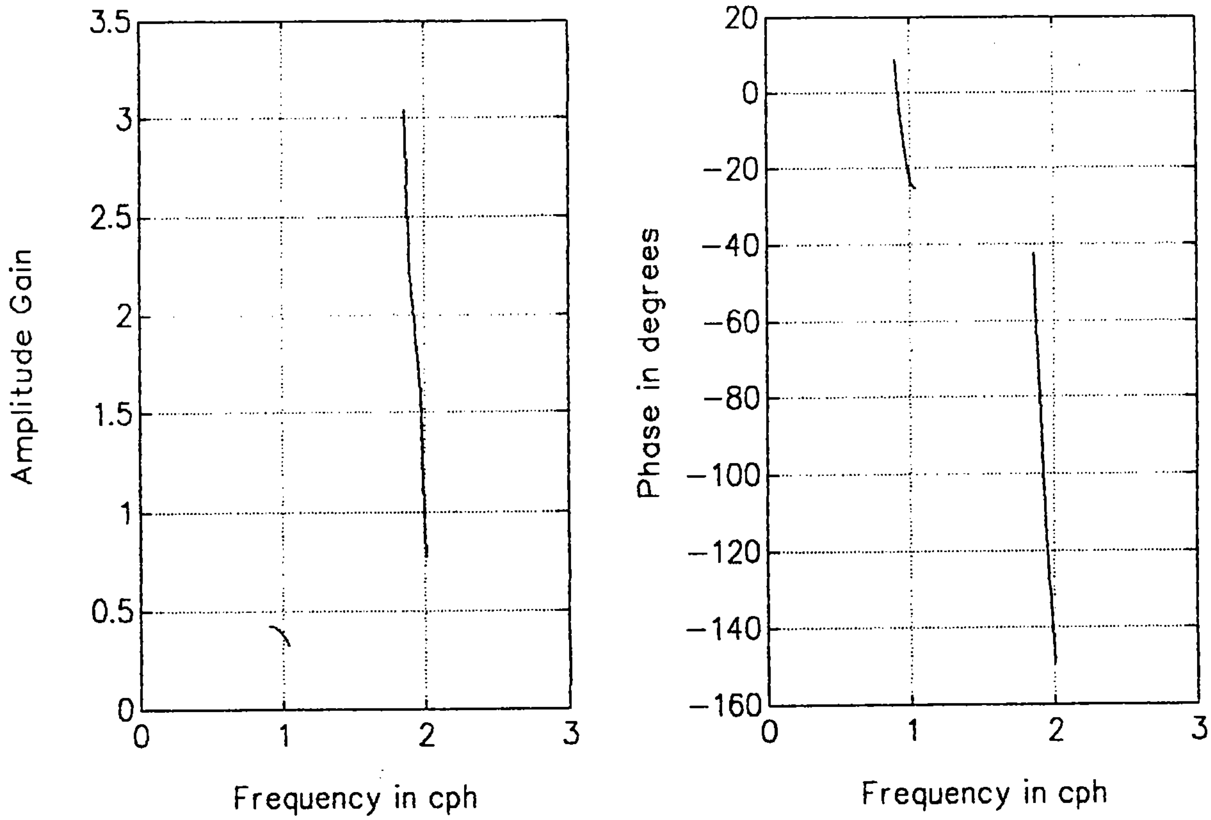


Figure T3 The admittance function to go from the gravitational potential forcing function (Munk and Cartwright, 1966) to the observed Stellwagen Basin Pressure (converted in cm elevation) is shown for the diurnal and semidiurnal tides. The admittance is plotted as an amplitude gain (top) and phase shift (bottom). The amplification due the Gulf of Maine-Bay of Fundy resonance is evident in the semidiurnal tidal band.

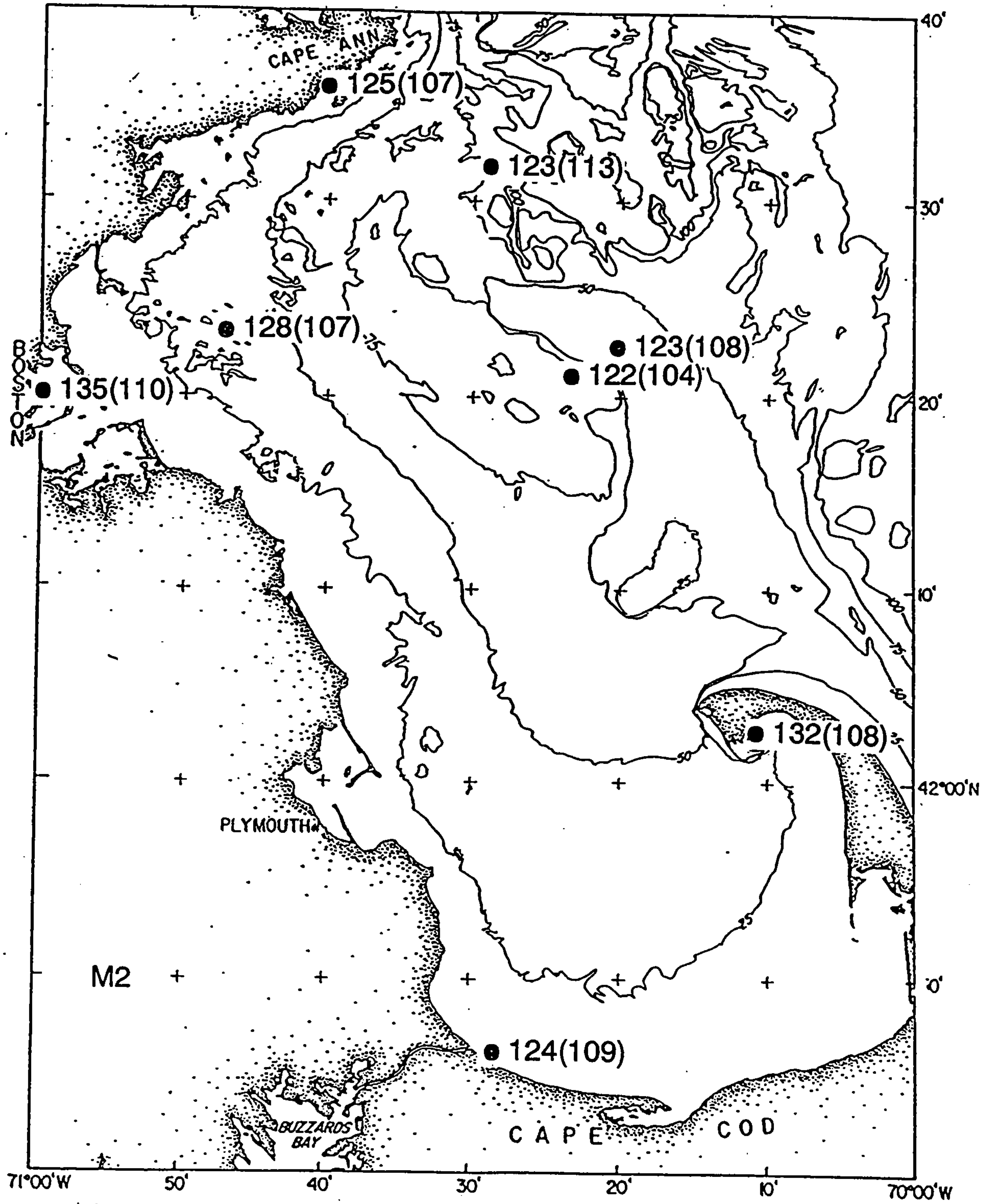


Figure T4 A cotidal chart of the M2 constituent of the tide shows the tidal elevation in cm and phase in Greenwich Epoch in parenthesis for the stations tabulated in tables T3 and T4. Uncertainties in the amplitude and phase estimates are about 0.1 to 1.0 cm and 0.2 to 1.0 degree depending on the record length .

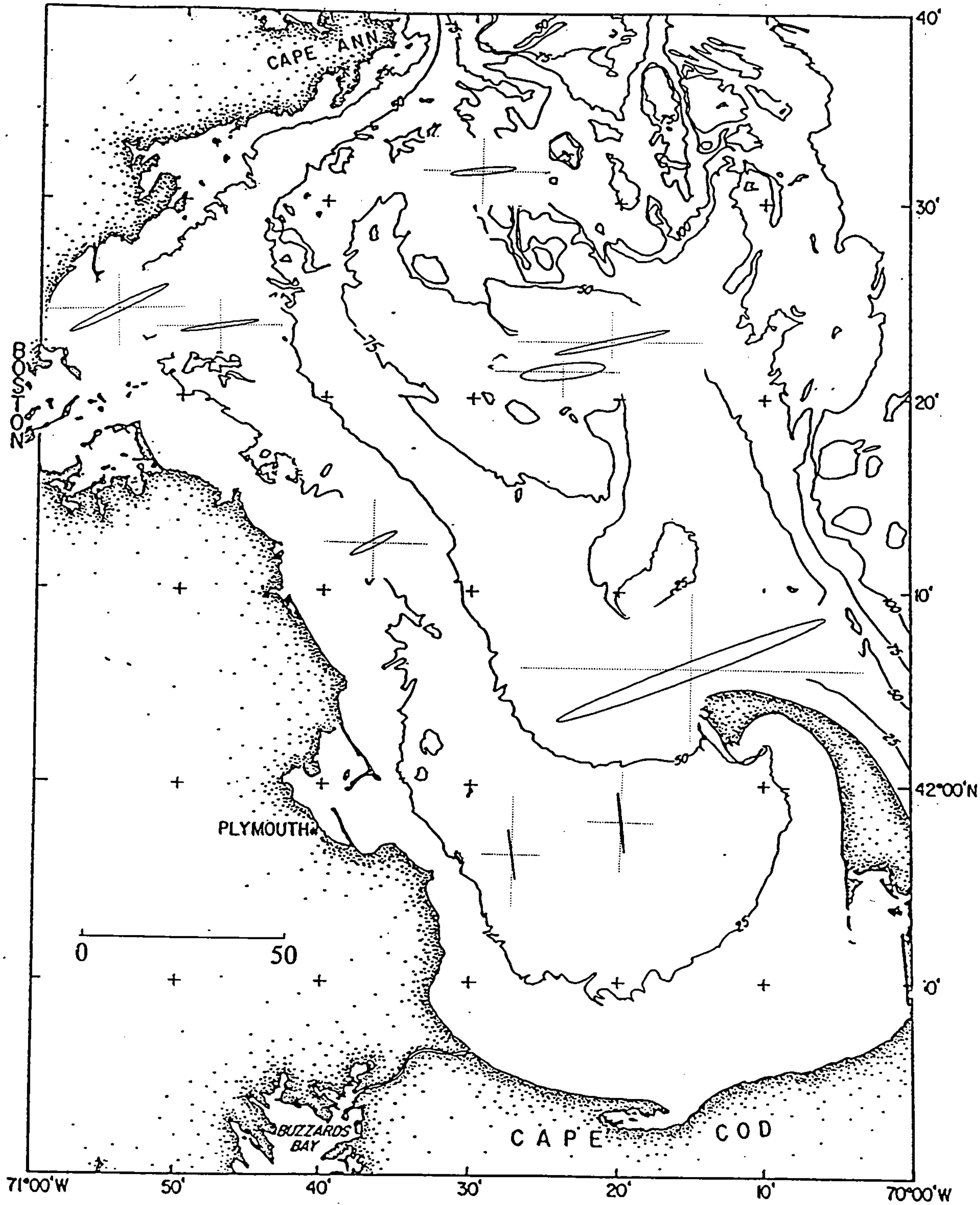


Figure T5 The current velocity ellipses from the surface (4 to 8 meters depth) for the winter analysis of the moorings (table T6). The center of the ellipse is the mooring location. The scale for 50 cm/sec is shown on the right margin. The velocity ellipses are shown scaled to about 3.3 times the magnitude of the tidal excursion calculated by integrating the observed currents at the location.

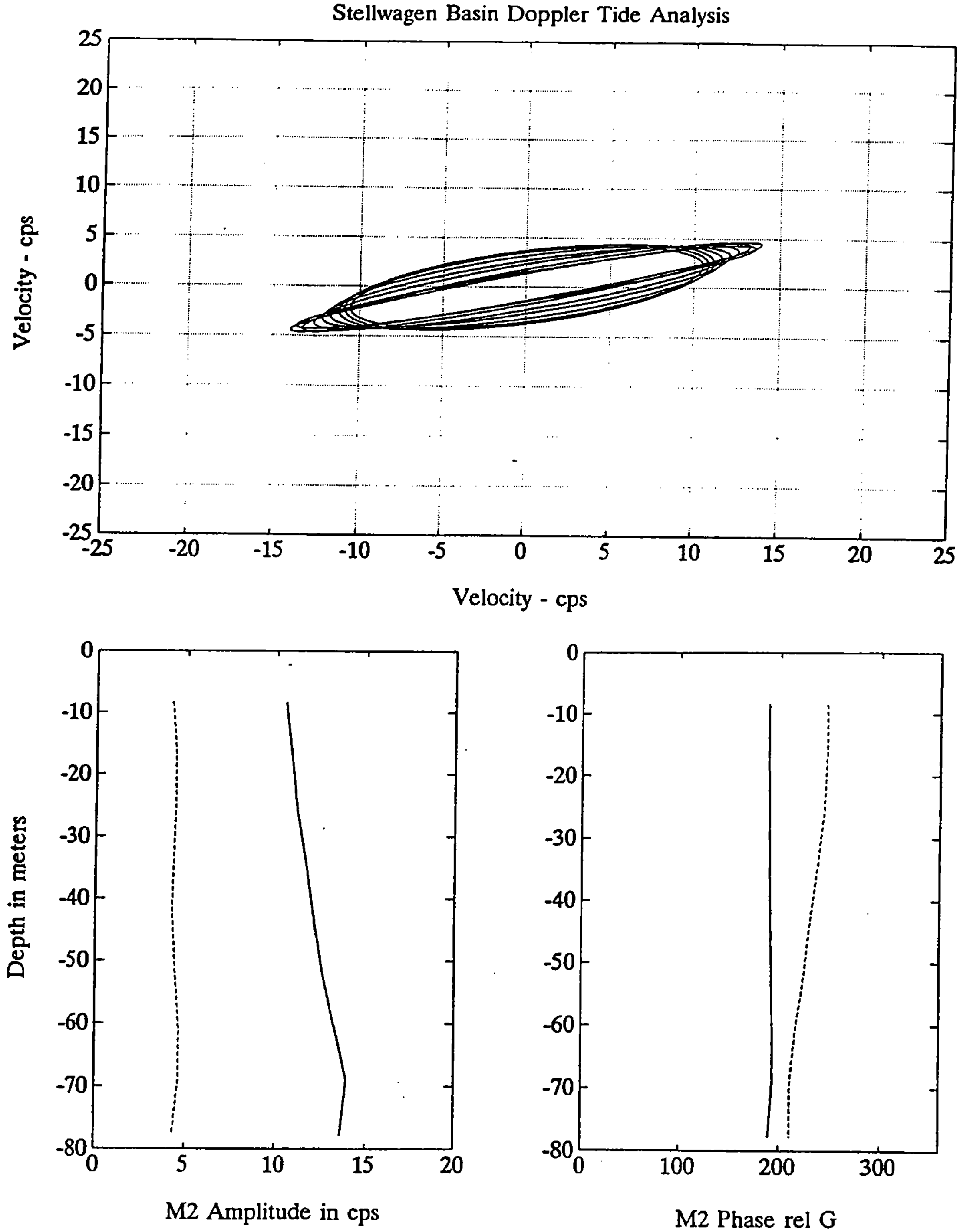


Figure T6 Winter 1991 (1 February to 15 March 1991) Stellwagen Basin Doppler profiler tidal analysis at the M2 frequency. The top panel shows the velocity ellipses (from table T7 part two) with the smaller amplitude, and rounder ellipses at the surface and a steady increase in major axis amplitude, and decrease in minor axis amplitude with depth. There is no significant turning of the ellipse. The two components (East solid and North dashed) amplitude and phase profiles are shown at the bottom. The currents are nearly barotropic.

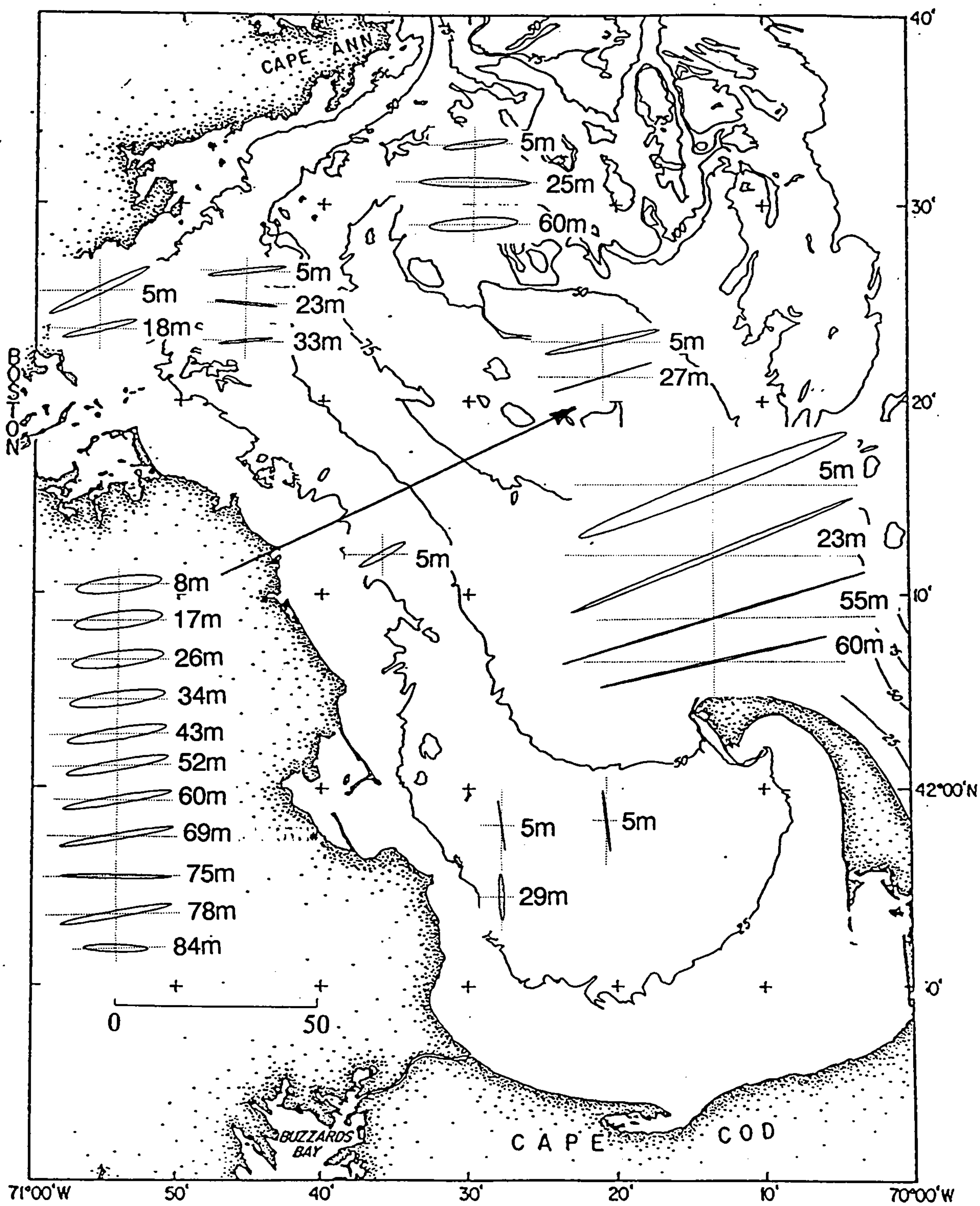


Figure T7 The vertical structure of the current ellipses for all the winter observations (table T6) at the moorings are shown.

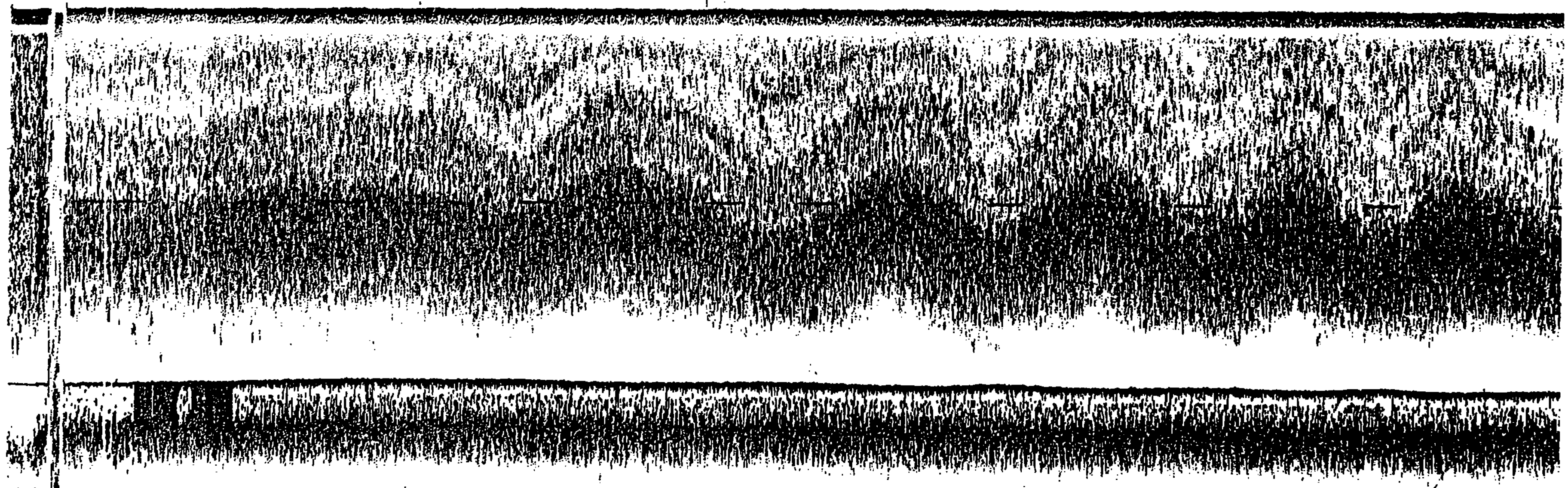


Figure T8 A depth sounder record taken on 24 July 1990 starting at 0910 UTC at the UNH Cape Cod mooring during servicing. The water depth is 40 meters, and the 10 meter vertical excursions of the pycnocline are clearly visible. The period of the waves is 7-15 minutes.

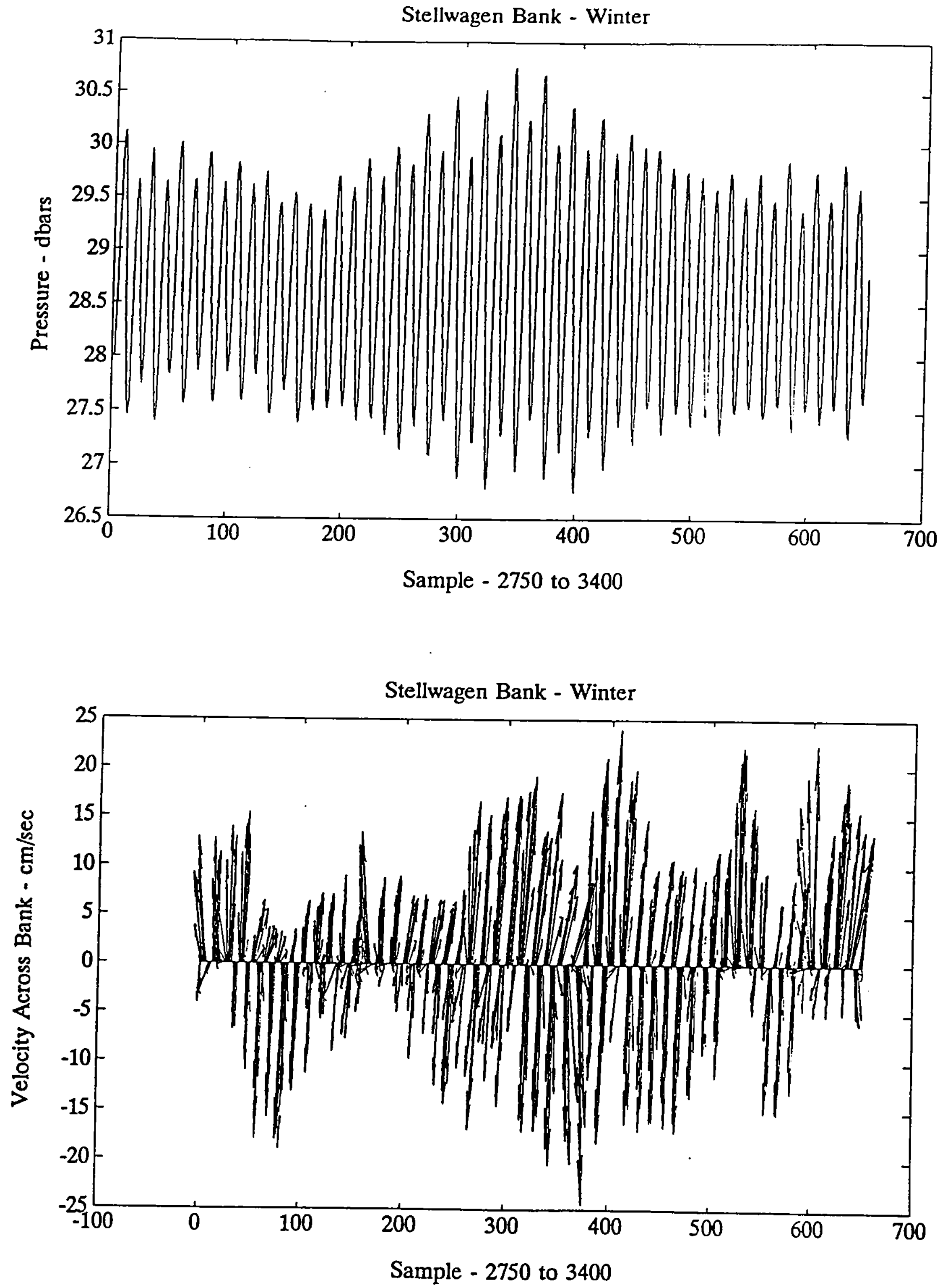
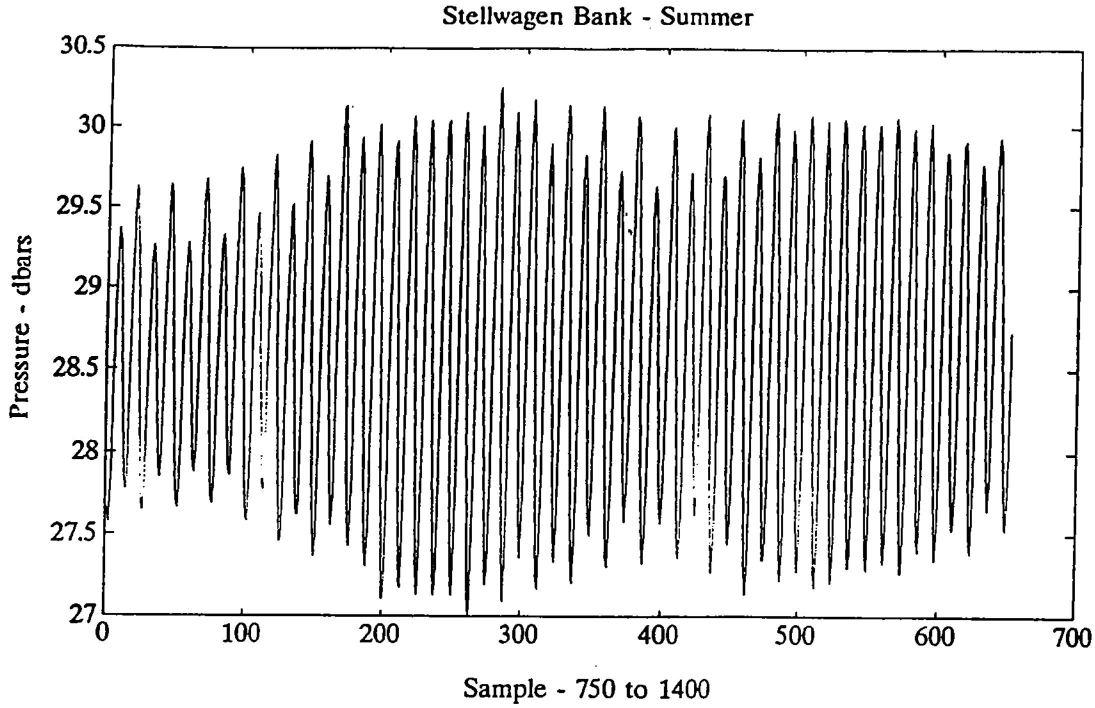


Figure T9 The bottom pressure observation (top) from mid- November 1990 to mid-December 1990 on Stellwagen Bank. The velocity (bottom) stick plot at 27 meters depth is drawn so that a vertical stick represents an on-off bank flow. The majority of the current is on-off bank.



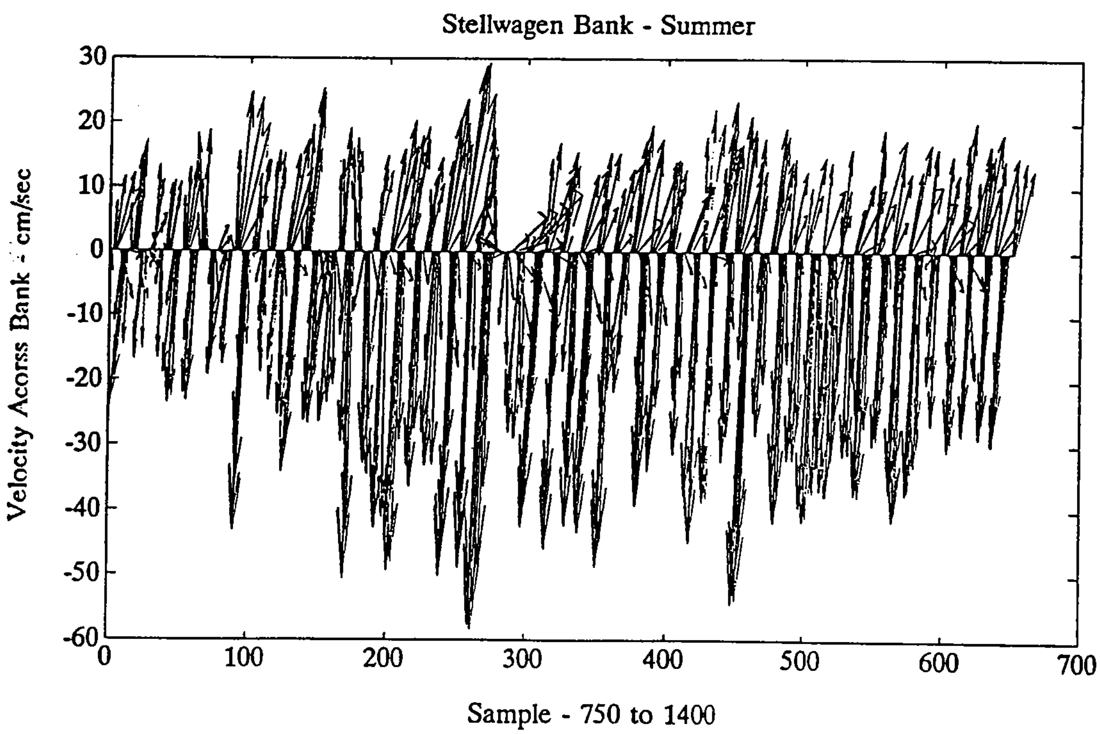


Figure T10 The bottom pressure observation (top) for the month of September 1990 on Stellwagen Bank. The velocity (bottom) stick plot at 27 meters depth is drawn so that a vertical stick represents an on-off bank flow. Note that the velocities in the "into Massachusetts Bay" direction are more than twice as large as during the winter (figure 9) with no accompanying larger flow out of Massachusetts Bay.

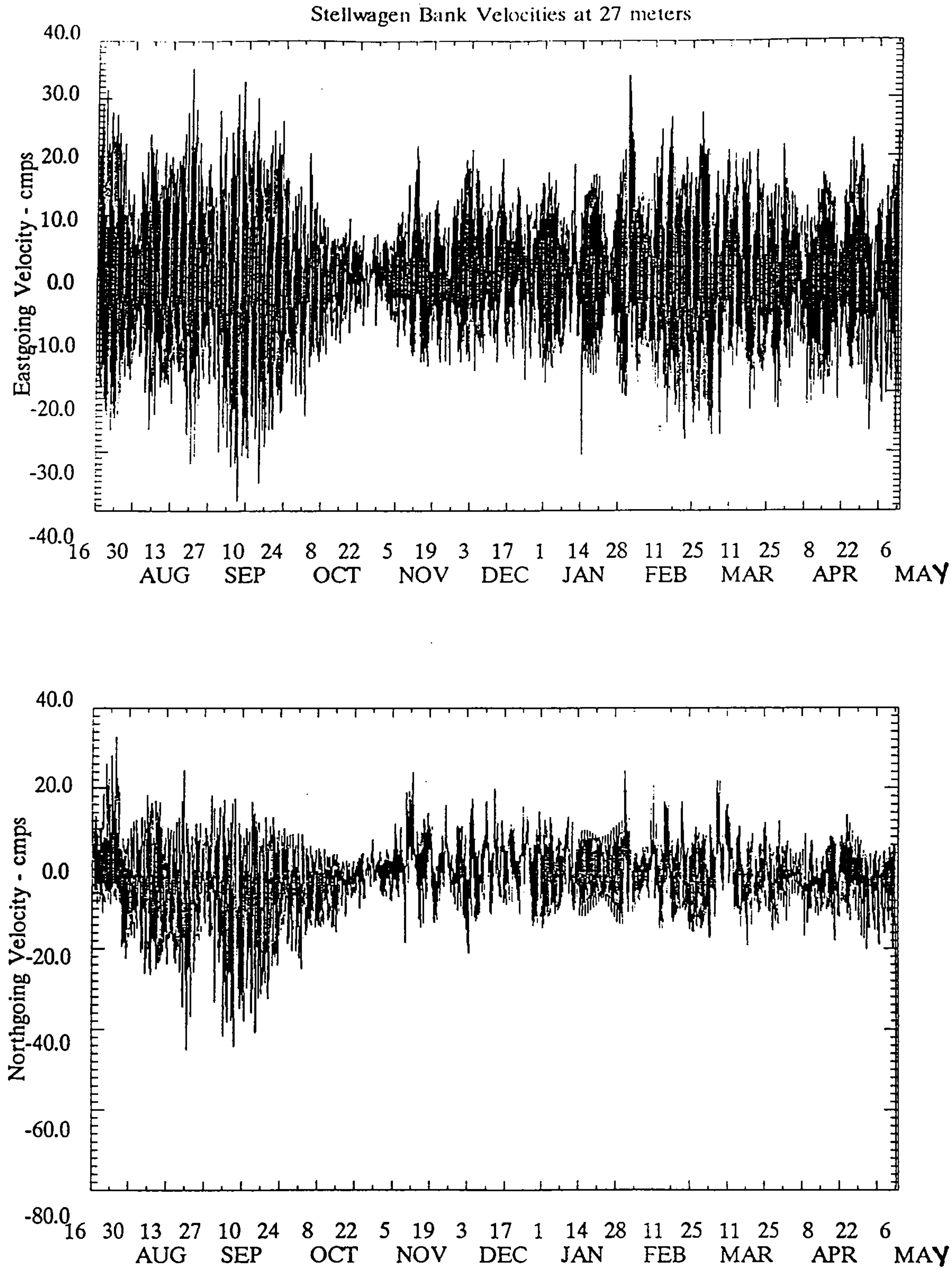


Figure T11 The two components of current on Stellwagen Bank, at 27 meters depth (2 meters off the bottom) from July 1990 through January 1991. The diurnal tides clearly dominate the record, and the decrease in amplitude of the currents when the water column becomes mixed during October is clearly evident.

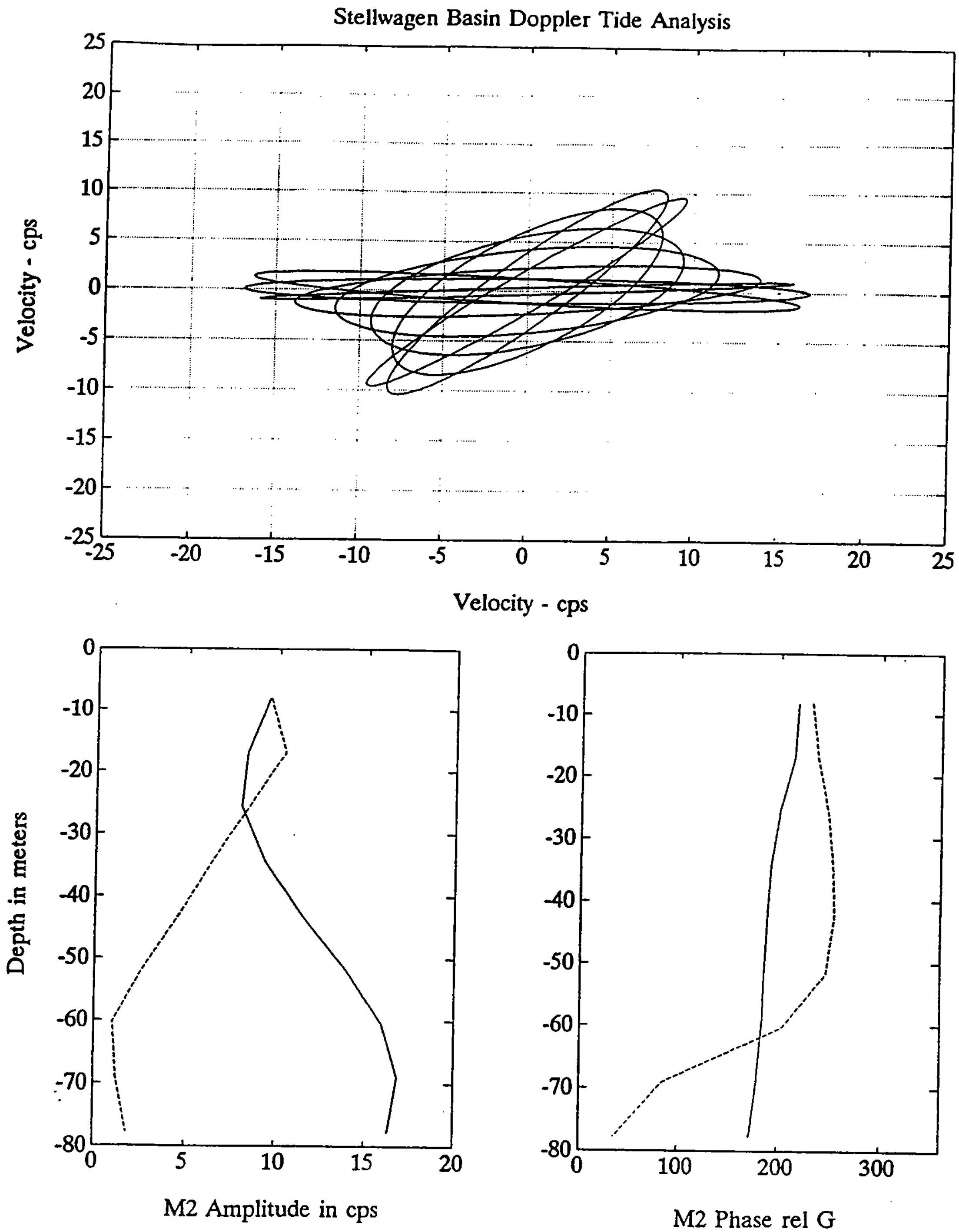


Figure T12 The Spring 1991 (15 March to 18 June 1991) Stellwagen Basin Doppler Profile tidal analysis at the M2 frequency. The tidal ellipses (top panel) now turn clockwise from the surface to the bottom. The ellipses get more round at mid depths and become more elliptical at the bottom. The rotation is about 50 degrees (see table T7). The amplitude and phase at the bottom indicate the baroclinic (internal wave) nature of the flow.

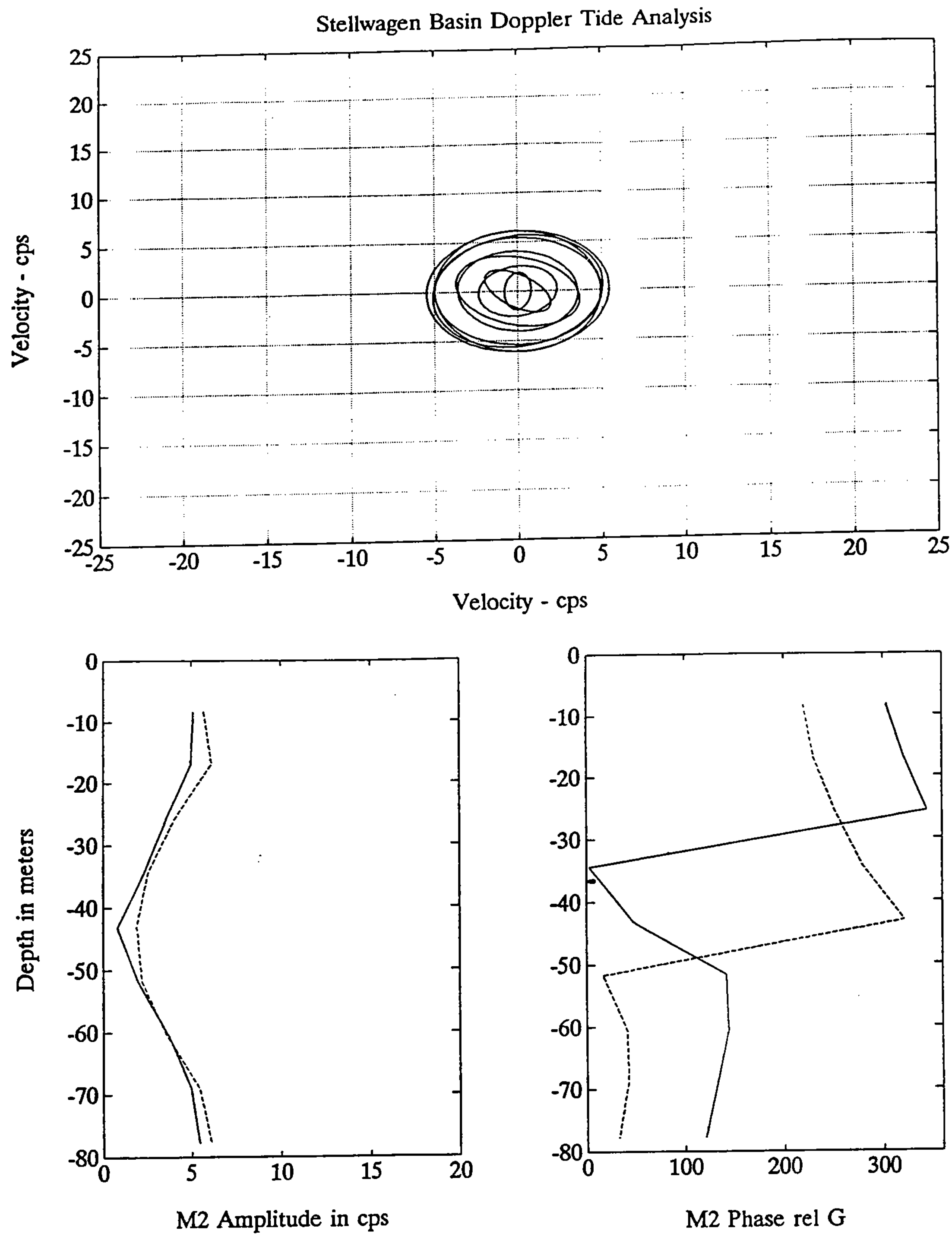


Figure T13 The Spring 1991 internal wave component at the M2 frequency at the Stellwagen Basin Doppler mooring was constructed by subtracting a predicted tide based on the winter analysis (figure T5) from the observed Spring tides (figure T12). The ellipses in the top panel show a nearly circular current with maximum amplitudes at the surface and bottom and a minimum at about 40 meters depth. This is shown at the bottom and the phase is observed to change by about 180 degrees, indicating that the top currents are out of phase with the bottom, or nearly a classic first mode internal wave velocity structure.